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END-TO-END TEST
of the
ELECTRON-PROTON SPECTROMETER

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Houston Aerospace Systems Division
Houston, Texas

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END-TO-END TEST
of the
ELECTRON-PROTON SPECTROMETER

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Preface

This report was prepared under NASA Contract NAS 9-11373 for the Electron-Proton Spectrometer (EPS) for Skylab.

Reported herein are the results of an end-to-end test program to demonstrate the proper operation of the spectrometer and its response to energetic protons and electrons.

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1.0 INTRODUCTION

A series of end-to-end tests were performed to demonstrate the proper functioning of the completed Electron-Proton Spectrometer (EPS). The purpose of the tests was to provide experimental verification of the design and to provide a complete functional performance check of the instrument from the excitation of the sensors to and including the data processor and equipment test set (EIS Paragraph 3.1.1.1.F). The primary verification of the detector shielding configuration design fell under the calibration program and is the report describing that program. The primary purpose of the end-to-end test was verification of system performance. Funding was provided to allow exposure of the Engineering Test Unit to energetic protons and electrons of various energies but only at a single angle of incidence, hence, experimental omnidirectional response functions could not be synthesized for the test unit. Lack of experimental omnidirectional response functions for the test unit precludes direct comparison with either analytic or experimental omnidirectional response functions determined in the calibration program. In addition, no normalization based on depletion depth variation can be utilized. In order to provide a basis for comparison, data taken at a similar angle of incidence in the calibration program were utilized to generate a monodirectional response function for each of the sensors used in the calibration program. In all cases, the angle of incidence was along the sensor shield centerline.

Each of the channels of the EPS was exposed to a calibrated beam of energetic particles and counts were accumulated for a predetermined period of time for each of several energies. The counts were related to the known flux of particles to give

a monodirectional response function for each channel. The measured response function of the test unit was compared to the response function determined for the calibration sensors from the data taken from the calibration program. The most meaningful way to compare two response functions is on the basis of their response to a standard spectrum over the same energy range. It would be preferable to use omnidirectional response functions in order to make a meaningful comparison. The monodirectional response function can only be used to give an indication of the relative response. In application the response function was multiplied by the differential particle spectrum and the resulting differential count spectrum was integrated over its entire energy range to give a count total. The resulting count totals were compared.

The tests entailed exposing the EPS to protons from the Variable Energy Cyclotron of Texas A&M University, College Station, Texas, and the Synchrocyclotron of Harvard University, Cambridge, Massachusetts, and to electrons from the 4.0 MeV Van de Graaff Accelerator at the National Bureau of Standards, Gaithersburg, Maryland.

2.0 EXPERIMENTAL RESPONSE FUNCTIONS

An experimental calibration program was undertaken to determine the omnidirectional proton and electron response functions of the various EPS sensors. Selected data from this calibration program were utilized to construct a monodirectional response function for each of the channels to be used as a standard against which the end-to-end test data could be compared.

2.1 Proton Response

Protons were obtained at two cyclotrons for the purpose of calibrating the various EPS sensors. Low energy protons, from 8 MeV to 43 MeV, were obtained from the Texas A&M University Variable Energy Cyclotron, College Station, Texas. Higher energy protons, from 52 MeV to 153 MeV, were obtained from the fixed energy Harvard University Synchrocyclotron, Cambridge, Massachusetts. Measurements were made at several discrete energies at the desired angle of incidence. In each case, specific energies were obtained by degrading and scattering selected beam energies.

Figure 1 is a diagram of the beam scattering configuration and proton flux calibration detector. The solid state detector used for flux calibration is a 2.0 mm thick lithium-drifted silicon detector. The collimator is a simple brass collimator with sufficient thickness to stop the incident protons and with a hole large enough to make any collimator effects insignificant relative to the transmitted beam. Commercial electronics, suitable for use with high quality solid state detectors, were utilized to amplify and count the detector

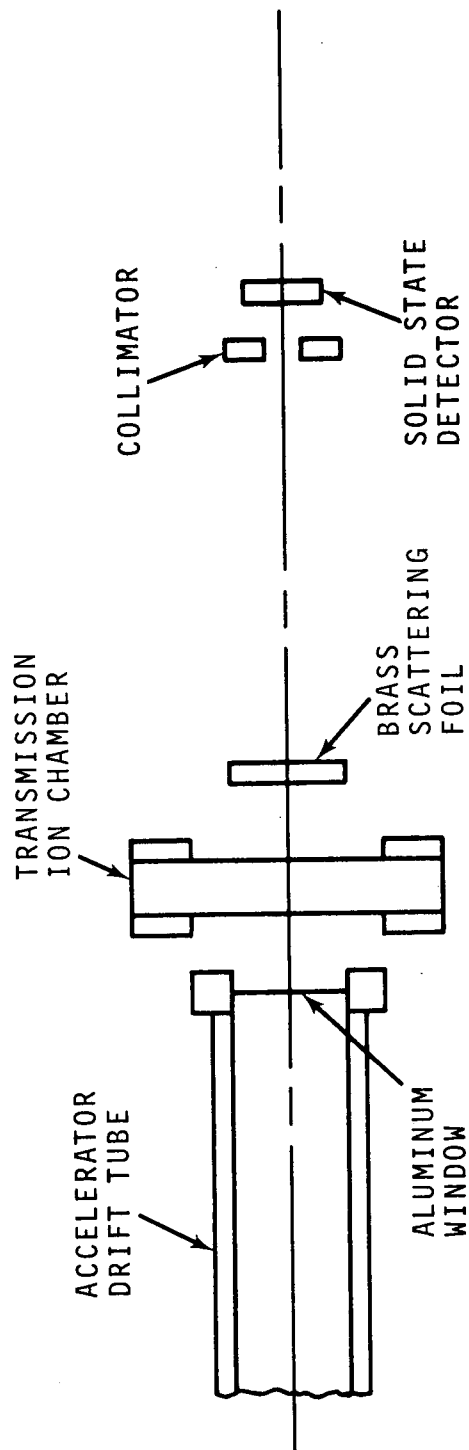


Figure 1. — Cyclotron Beam Scattering Configuration with Proton Flux Calibration Detector

output pulses. A bias of 500 V was applied to the detector and a pulse shaping time constant of 1.0 μ sec was utilized in the amplifier. At Texas A&M a pair of stacked 5.0 mm lithium-drifted silicon detectors, operated at 1000 V, were used for proton energy determination. A 4096 channel pulse height analyzer was used to record the output spectra of the detectors. In order to prevent pile-up of pulses in the electronic apparatus a low flux of protons was maintained. Energy calibration was achieved at Harvard University by range measurements utilizing calibrated aluminum foils and range-energy tables.

For each beam energy configuration, a calibration run was made to determine the beam energy and particle flux at the experimental location. Afterwards, the calibration detector was replaced with the EPS calibration sensor for an experimental run as shown in Figure 2. The EPS calibration sensor consists of one of five shields made to the same specifications as the shields used on the flight system and a 2.0 mm cubical detector selected from the test detectors undergoing testing and evaluation. A special electronics system was built to have the same specifications as the preamplifier and amplifier of the flight system plus a special pulse stretcher to allow analysis by commercial electronics. The detector was operated at a bias of 350 V and a pulse shaping time constant of 360 nsec was used. The multichannel analyzer was used to record the output spectra of the detector. A fast threshold monitor was used to provide a correction for pulses lost due to analysis

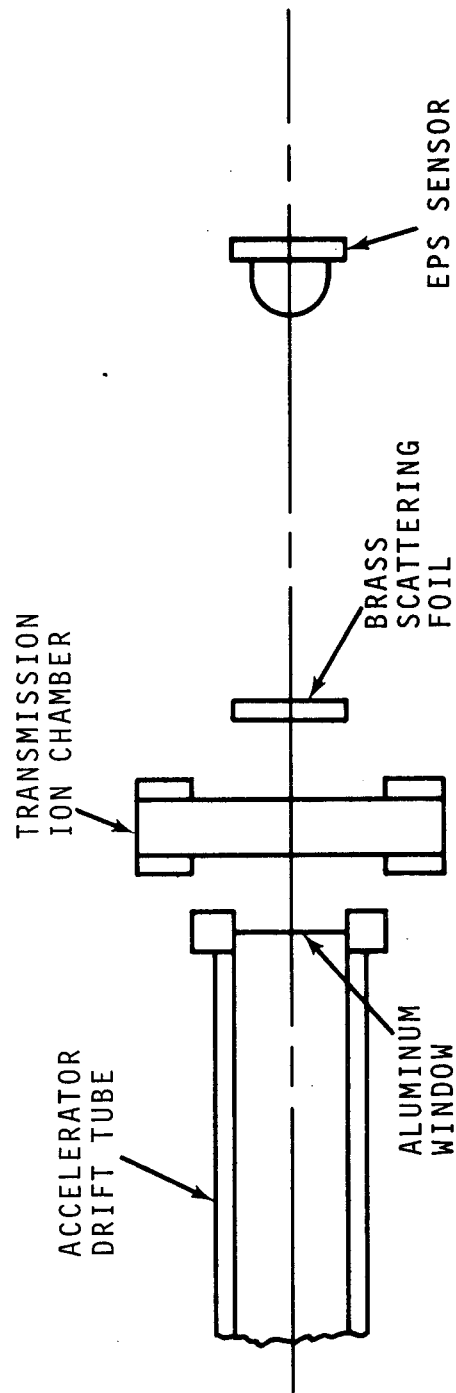


Figure 2. — Cyclotron Beam Scattering Configuration with EPS Calibration Sensor.

dead time. Spectra were recorded for each of several energies with each shield. The pulses greater than 2.0 MeV (and 1.0 MeV in channel 6) were totalized in each spectrum and divided by proton flux to provide a basis for comparison with the discriminator output of the Engineering Test Unit in the End-to-End Test. The data values are given in Table I. The responses are plotted for each of the channels in Figures 3 - 8 as a function of proton energy.

2.2 Electron Response

Electrons were obtained at two Van de Graaff accelerators for the purpose of calibrating the EPS. Low energy electrons, from 0.5 MeV to 2.75 MeV, were obtained from the NASA/MSU 3.0 MeV accelerator in Houston, Texas. Higher energy electrons, from 2.0 MeV to 4.2 MeV, were obtained from the 4.0 MeV accelerator at the National Bureau of Standards, Gaithersburg, Maryland. No higher energy electrons were available in useable quantities from nonpulsed machines. As in the case of the proton measurements, the electrons were allowed to impinge on the detector, normal to the detector's top surface.

Figure 9 is a diagram of the beam scattering configuration for the low energy beam at MSC and an EPS sensor. The electron flux was measured in the same way as the proton flux, with a collimated 2.0 mm thick lithium-drifted silicon detector. The collimator is a simple brass collimator. A series of collimators, from 1/8" diameter to 5/8" diameter, was used to assure that any collimator effects were insignificant relative to the transmitted beam. Typically, a 1/4" diameter was sufficient. The measurements were made

Table I Head-On Response - Protons

Proton Energy	EPS Channel - Cts/Flux					
	1	2	3	4	5	6
153	.0253	.0266	.0266	.0287	.0311	.0352
130	.0320	.0326	.0321	.0322	.0327	.0357
111	.0344	.0345	.0345	.0343	.0344	.0369
90.	.0370	.0373	.0370	.0370	.0377	.0393
85					.0408	.0423
79.4					.0364	.0376
76.8					.0194	.0202
73.2	.0393	.0387	.0392	.0388	.0040	.0042
52	.0397	.0404	.0402	.0410	--	--
42.9	.0399	.0406	.0410	.0418		
41.2				.0422		
40.1	.0379	.0383	.0391	.0385		
38.9				.0133		
35.3	.0401	.0400	.0408	.000		
33.6			.0394			
31.4			.0393			
29.8			.0404			
28.3			.0408			
23.3		.0416	.0152			
21.4	.0410	.0425				
16.3	.0415					
15.6	.0431					
12.9	.0420					
12.1	.0430					
8.5	.0081					

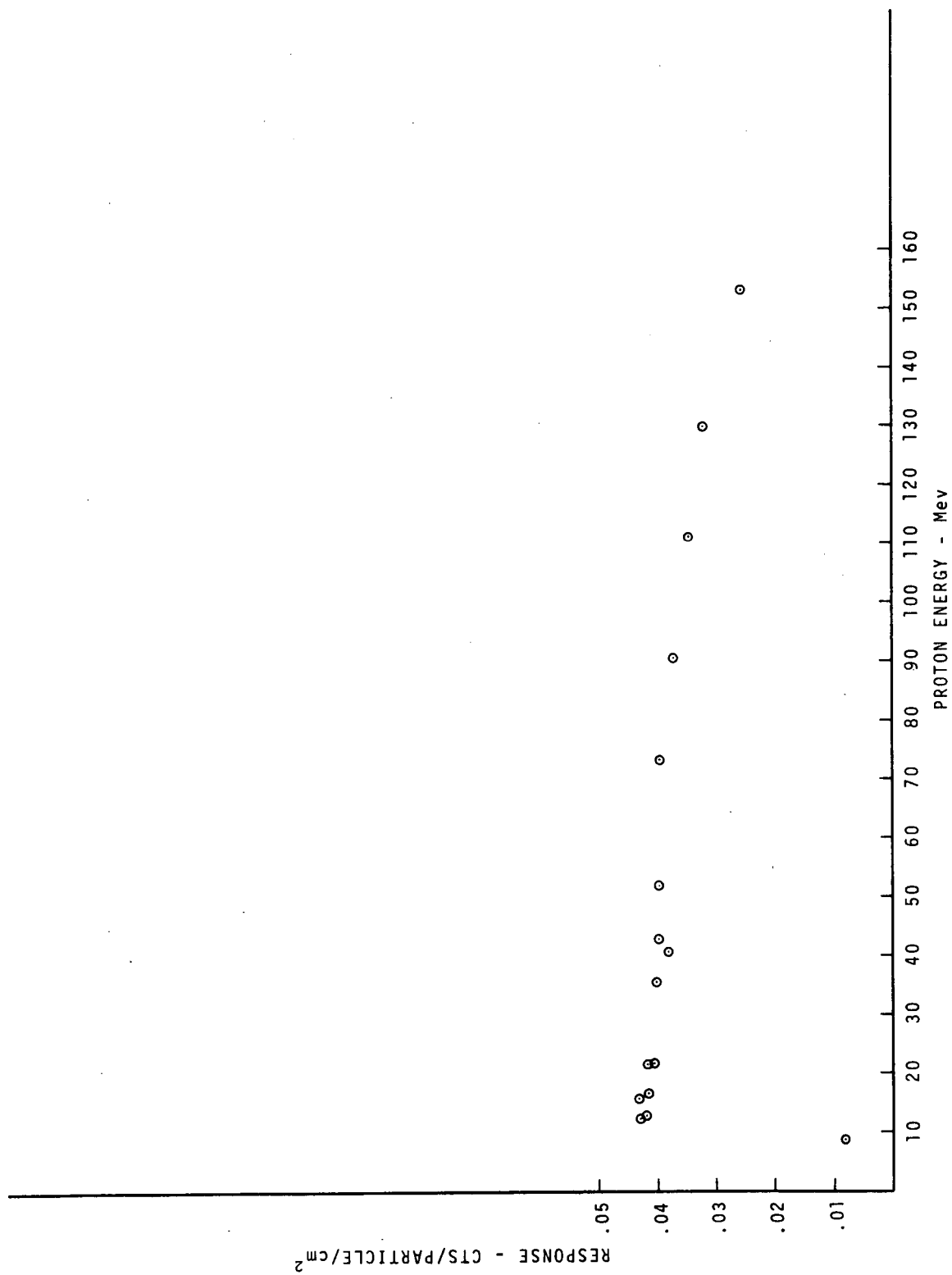


Figure 3. — Head-On-Response, Channel 1, Protons.

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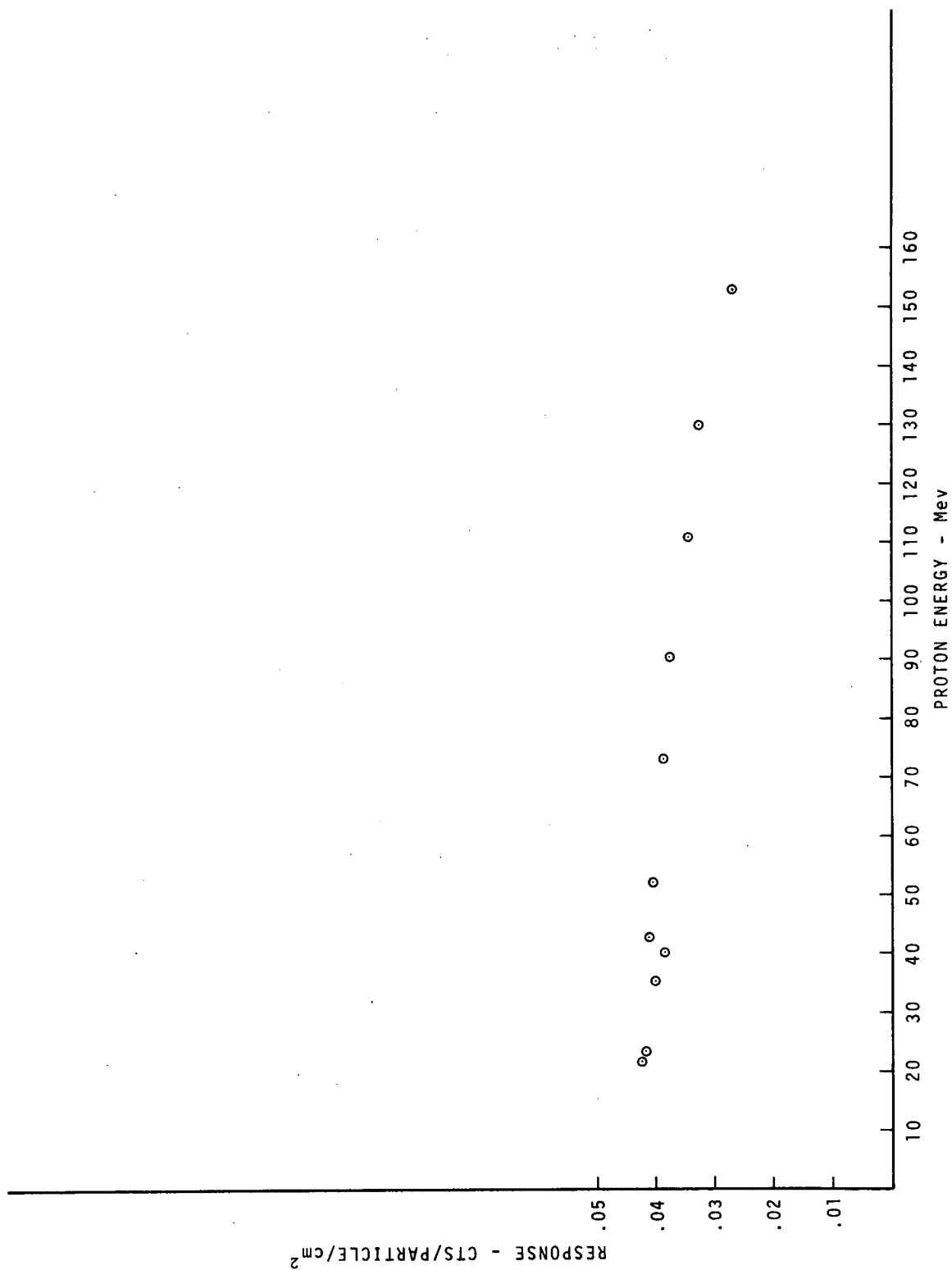


Figure 4. — Head-On-Response, Channel 2, Protons.

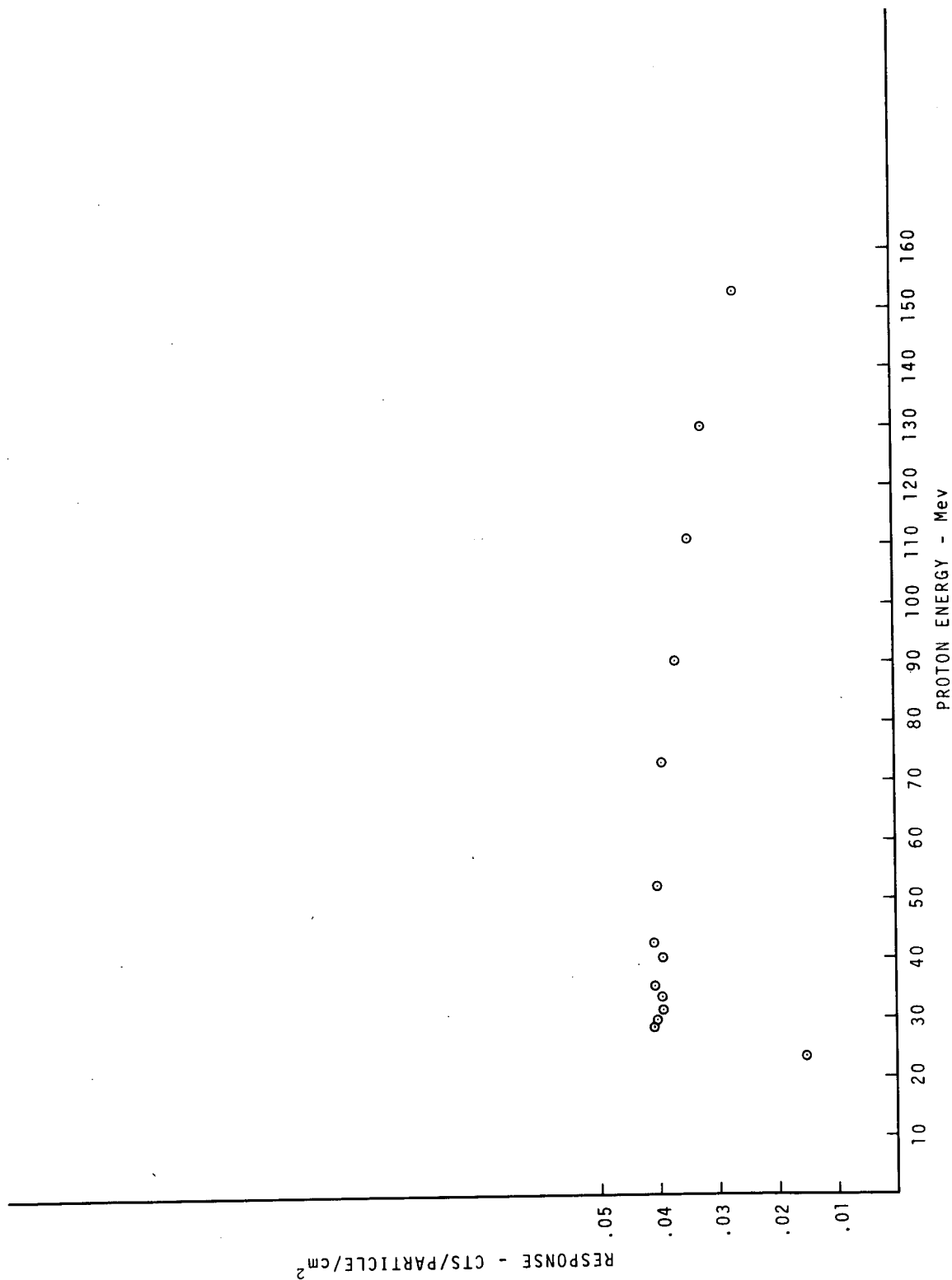


Figure 5. — Head-On-Response, Channel 3, Protons.

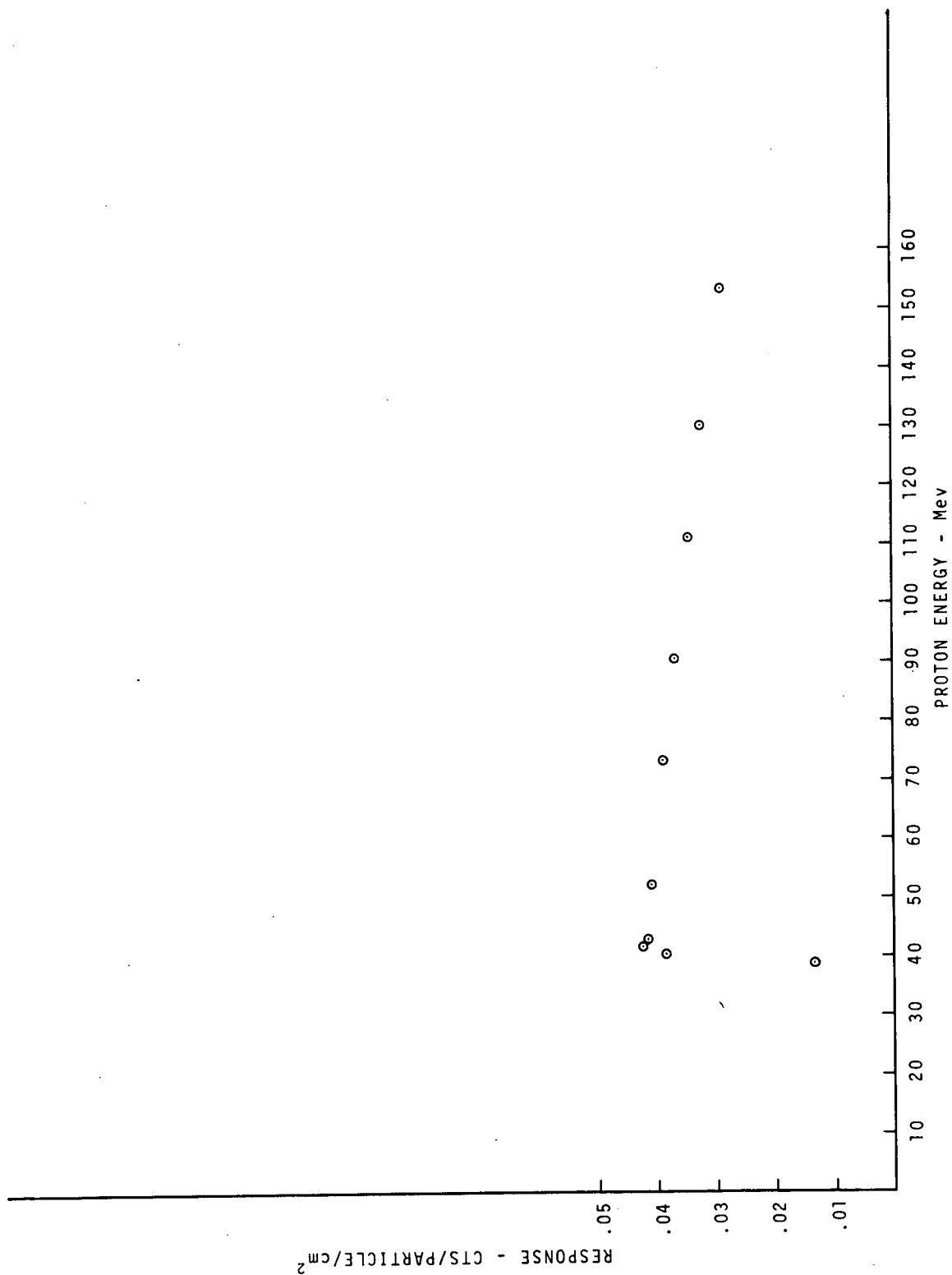


Figure 6. — Head-On-Response, Channel 4, Protons.

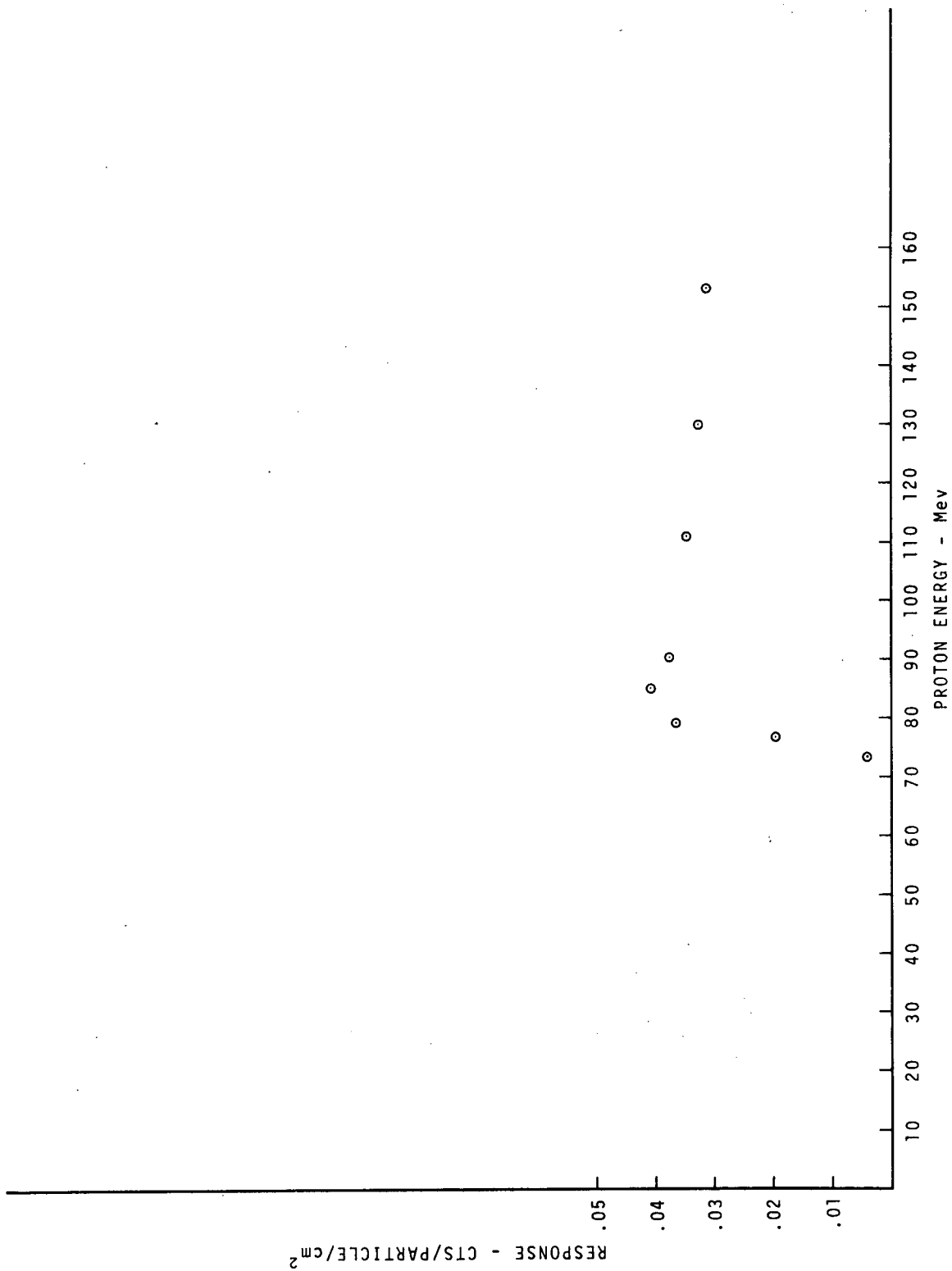


Figure 7. — Head-On-Response, Channel 5, Protons.

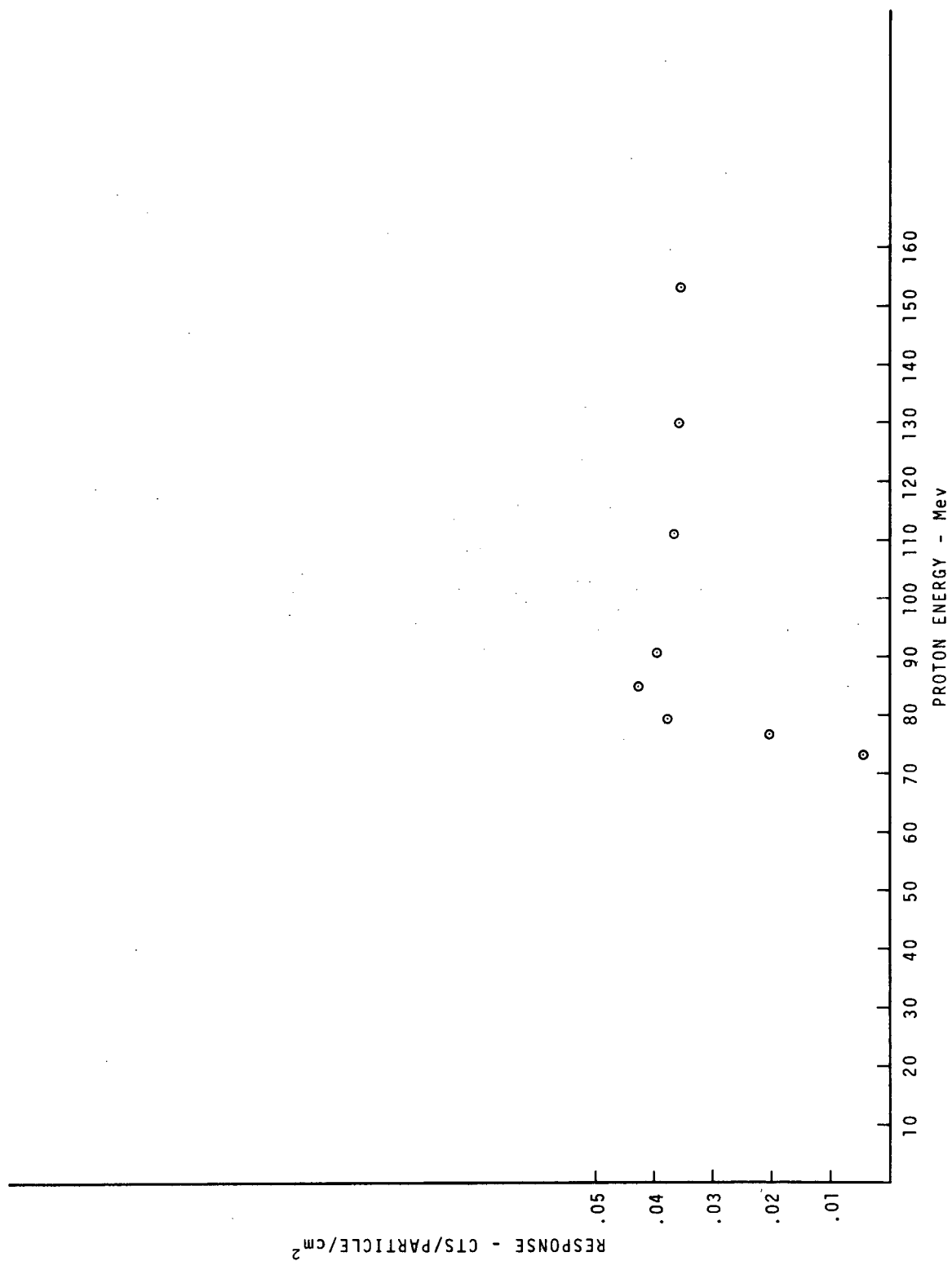


Figure 8. — Head-On-Response, Channel 6, Protons.

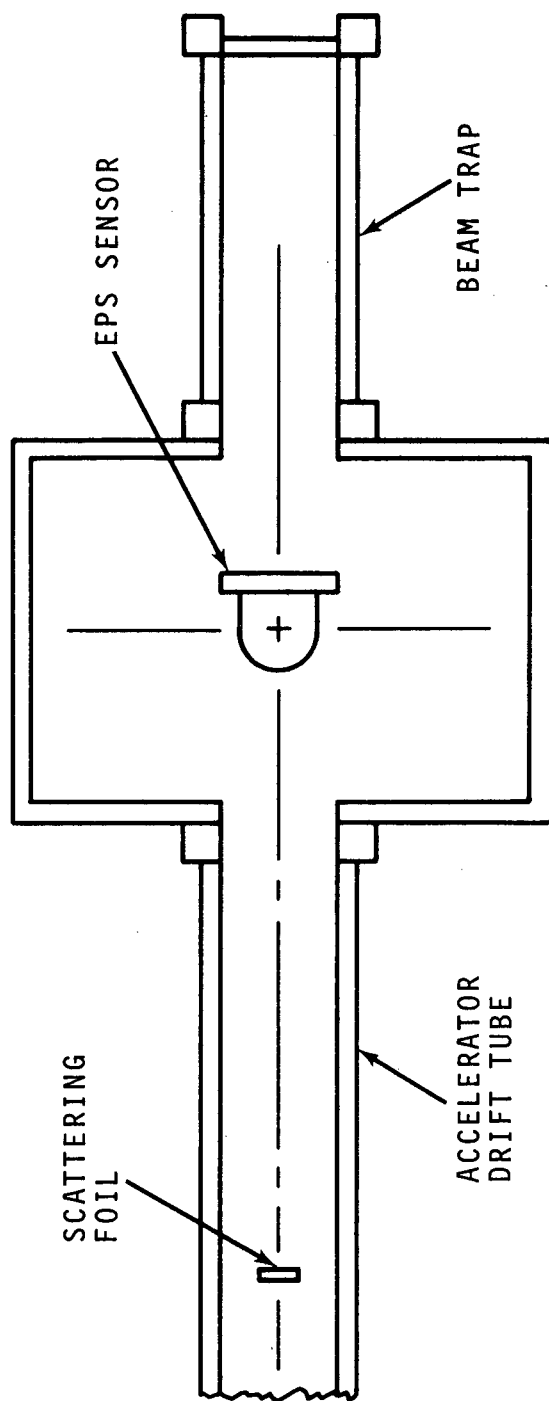


Figure 9. — Low Energy Electron Beam Configuration.

in a vacuum because of excessive energy losses in the exit window and air path at very low energies. Measurements were made in this configuration from 0.5 MeV to 2.75 MeV.

Figure 10 is a diagram of the beam scattering configuration for the high energy beam at NBS and an EPS sensor. The electron flux and energy were measured with a collimated 5.0 mm thick lithium-drifted silicon detector. The measurements were made in air for the higher energies because of the easier access to the equipment. Measurements were made in this configuration from 2.0 MeV to 4.1 MeV. The overlap region from 2.0 MeV to 2.75 MeV showed there were no deleterious effects due to the exit window and air path.

For each beam energy, a calibration run was made to determine the beam profile, beam energy and particle flux at the experimental location. Afterwards, the calibration detector was replaced with the EPS sensor for an experimental run. The electronics system used in the proton measurements was also used for the electrons. However, in the analysis of the data, a 200 keV discriminator level was used to provide a comparison with the electron output of the Engineering Test Unit in the End-to-End Test. Pulse height spectra were recorded for each of the several energies with each shield. The pulses greater than 200 keV were totalized in each spectrum and divided by the electron flux. The data values are given in Table II. The responses are plotted in Figures 11 - 14. The channel 4 values are replotted in Figure 15 on an expanded scale to better show the values.

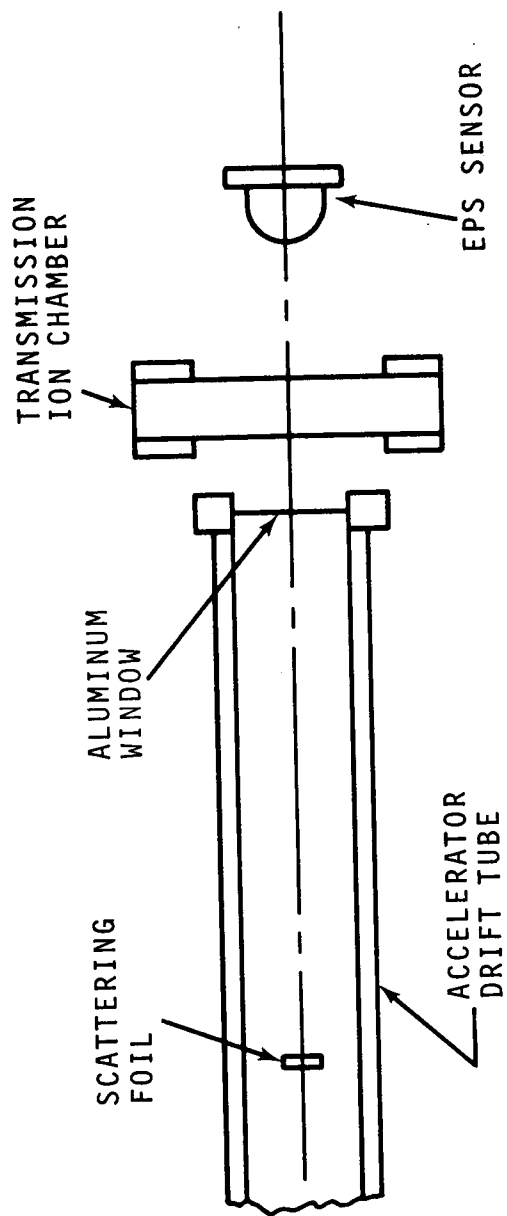


Figure 10.— High Energy Electron Beam Configuration.

Table II Head-On Response - Electrons

Electron Energy	EPS Channel - Cts/Flux			
	1	2	3	4
4.08				.00271
3.88			.0473	.00144
3.76	.0503	.0516	.0450	.00094
3.69		.0506	.0440	.00065
3.38	.0508	.0495	.0390	
3.00	.0527	.0458	.0315	
2.75	.0532	.0437		
2.71	.0527	.0410	.0235	
2.50	.0560	.0369		
2.42	.0529	.0333	.0155	
2.15	.0551	.0254	.00765	
2.00	.0537	.0203		
1.50	.0471	.0033		
1.25		.00045		
1.00	.0315			
.75	.0119			
.57	.0014			
.50	.00038			

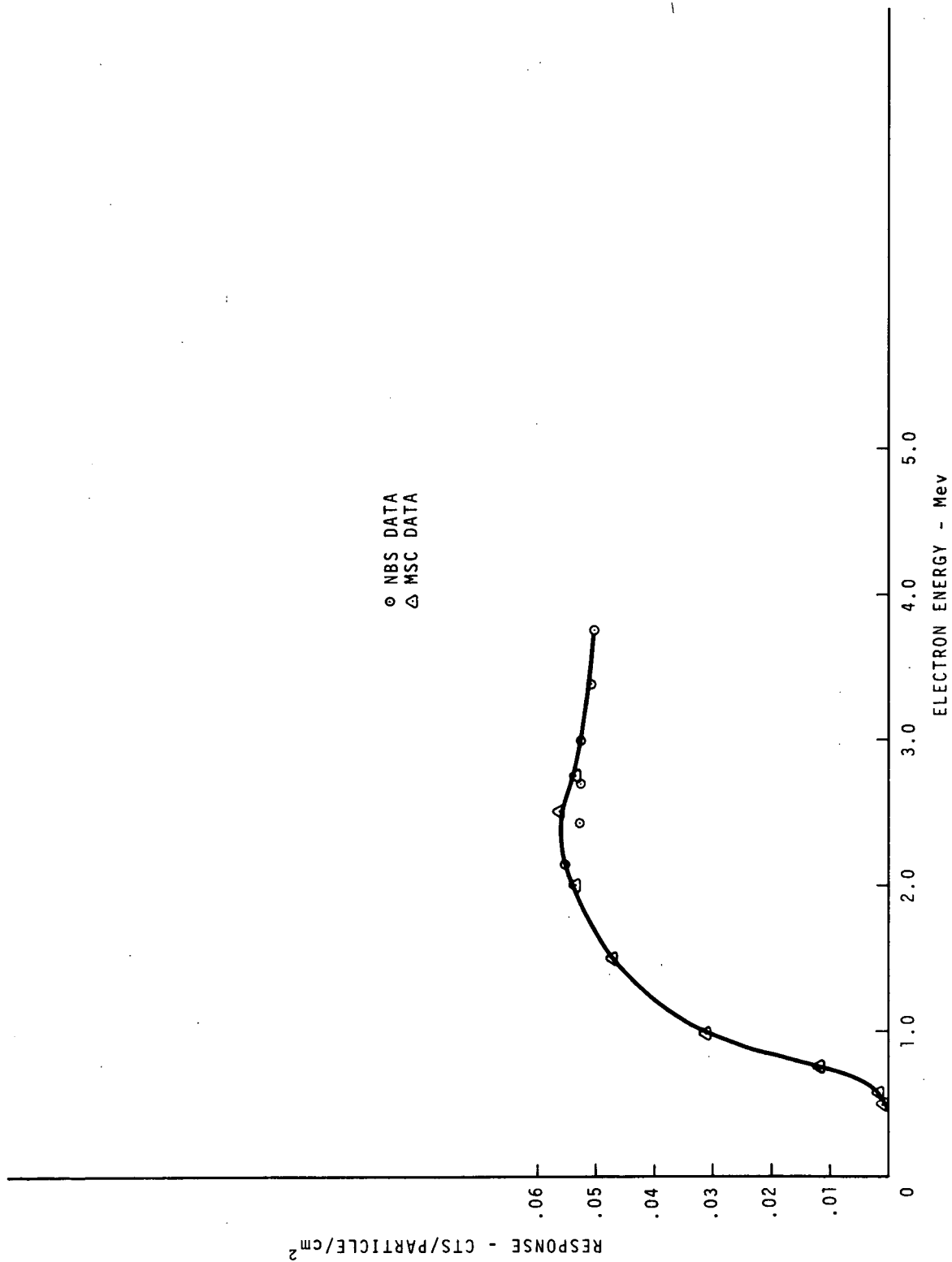


Figure 11. — Head-On-Response, Channel 1, Electrons

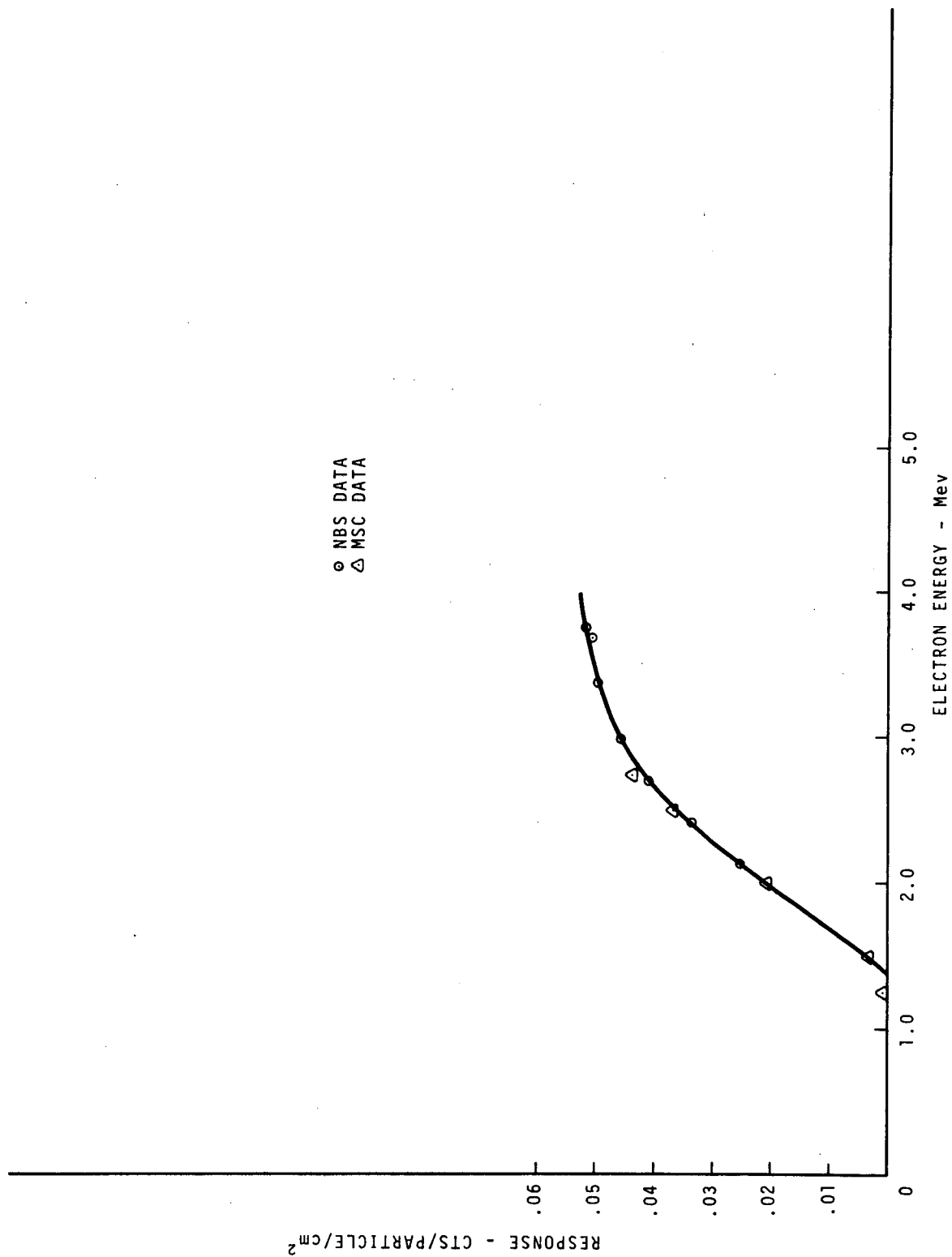


Figure 12.-- Head-On-Response, Channel 2, Electrons.

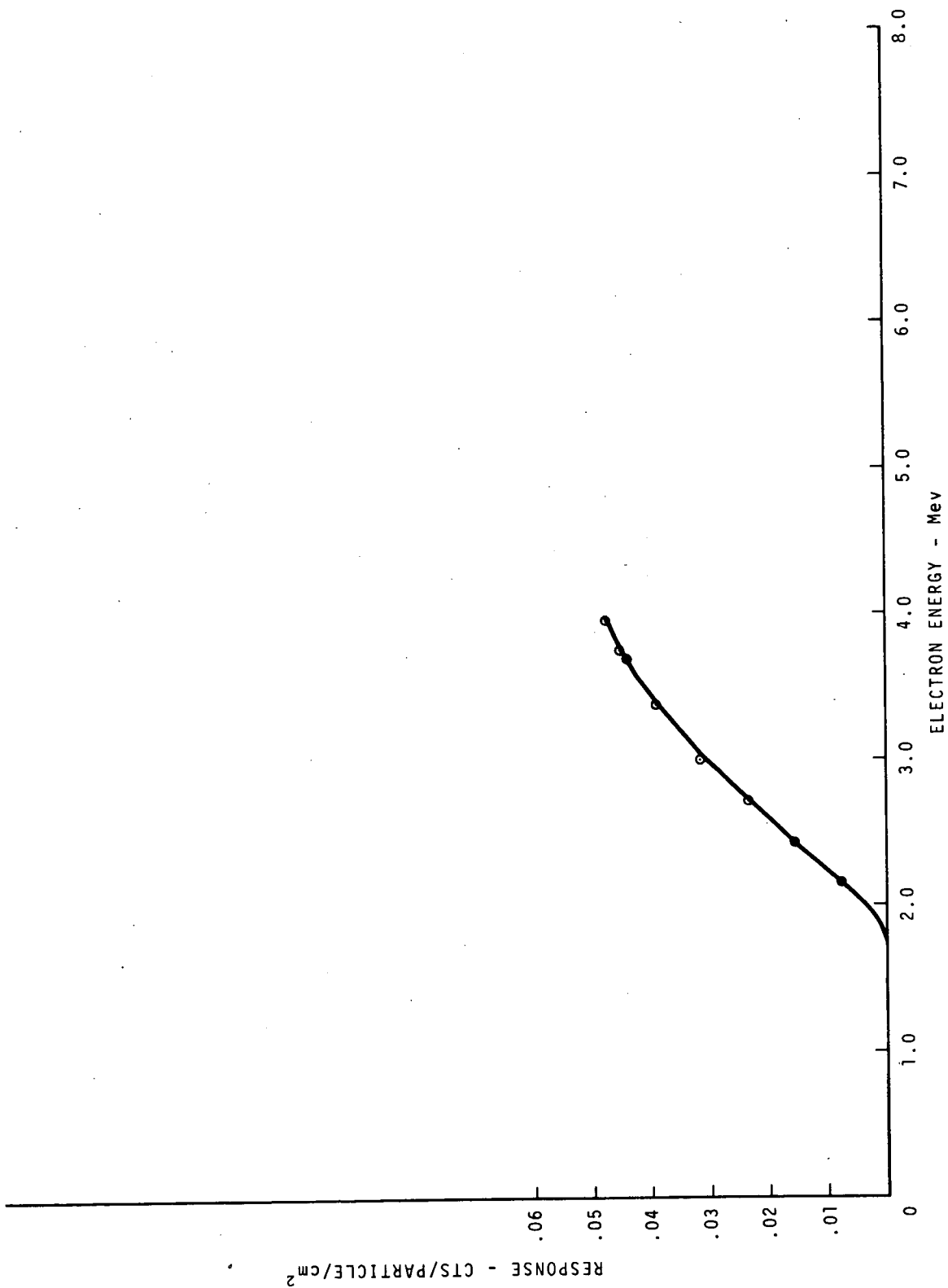


Figure 13. — Head-On-Response, Channel 3, Electrons.

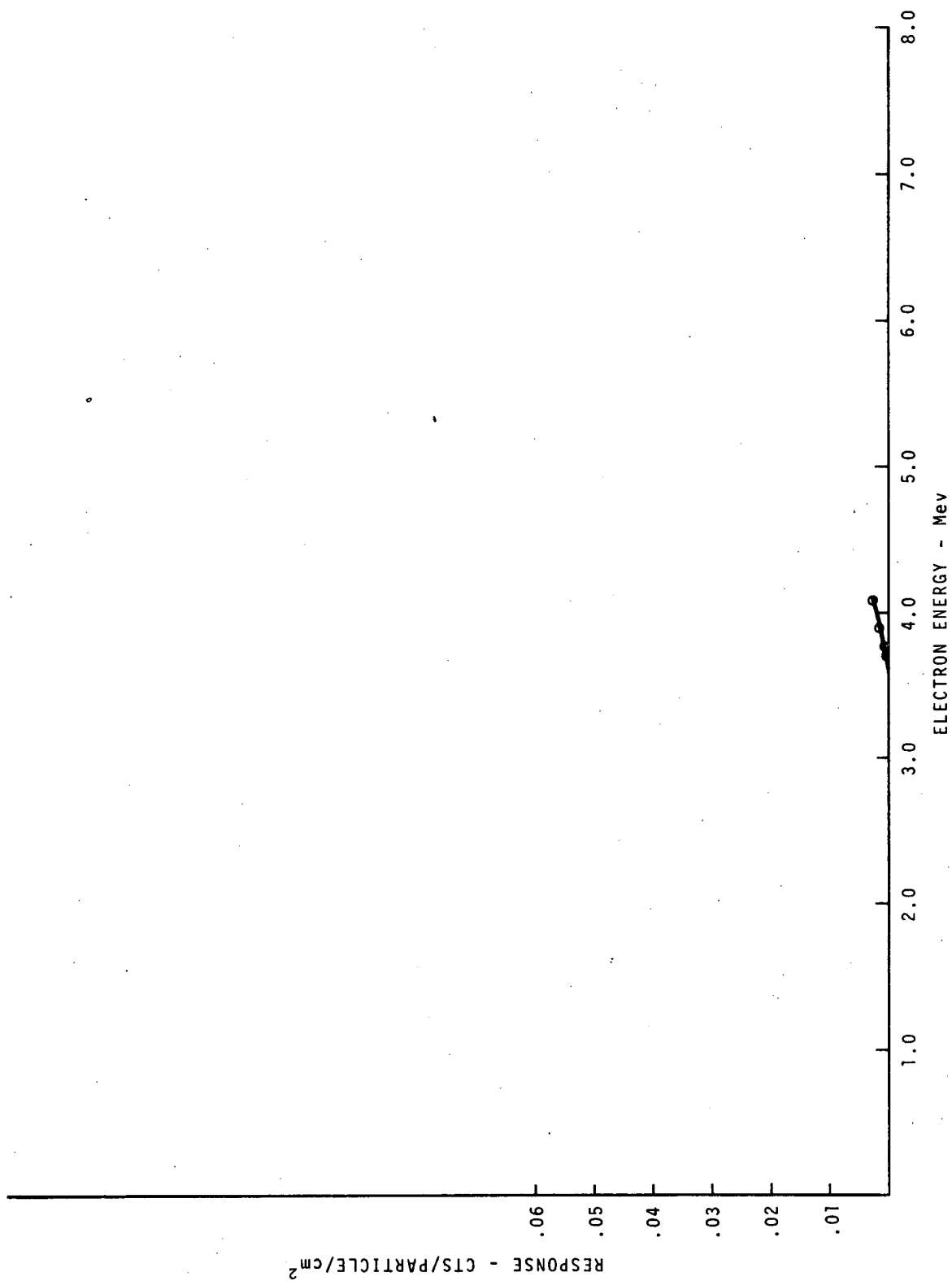


Figure 14. -- Head-On-Response, Channel 4, Electrons.

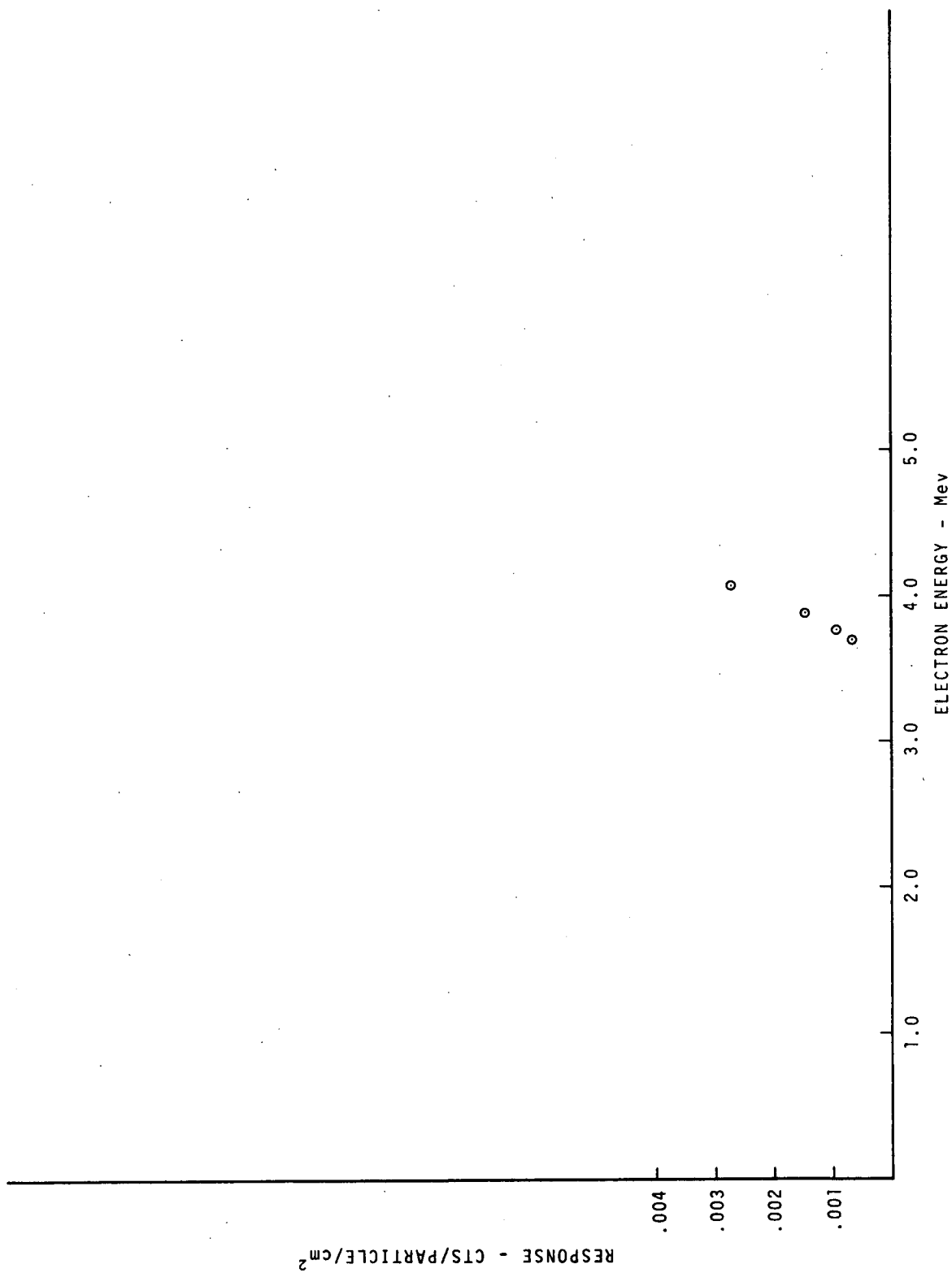


Figure 15. — Head-On-Response, Channel 4, Electrons.

3.0 END-TO-END TESTS

A series of end-to-end tests was performed to demonstrate the proper functioning of the completed EPS. The Engineering Test Unit (ETU) was used for the tests. Five 2.0 mm cubical detectors were selected from the detectors undergoing testing and evaluation and installed in the ETU. For the purposes of this test, protons and electrons were allowed to impinge upon each of the ETU sensors, in turn, normal to the top surface of the detectors.

3.1 Proton Test

Protons were obtained at the two cyclotrons listed in section 2.1, viz, at Texas A&M University and at Harvard University. The various channels of the ETU were exposed to essentially the same energies that were used in the calibration tests, but not as many values were used. Figure 16 is a diagram of the proton beam scattering configuration and the ETU. The End-to-End Test was run concurrently with the EPS calibration program, hence it was possible to use the same beam calibration discussed in section 2.1. Since the EPS has its own data processor built in, no pulse height spectra were available. The processor accumulates counts above a predetermined discriminator level (2.0 MeV for channels 1 - 5 and 1.0 MeV for channel 6) for a predetermined length of time. The number of counts is available upon interrogation. The beam intensity was monitored for the same period of time to permit calculation of the channel response in counts/particle/cm². The results are given in Table III. The responses are plotted as individual data points for each of the channels in Figures 17 - 22. The calibration response for each channel, determined in section 2.1, is plotted on the same graphs as a solid line for comparison.

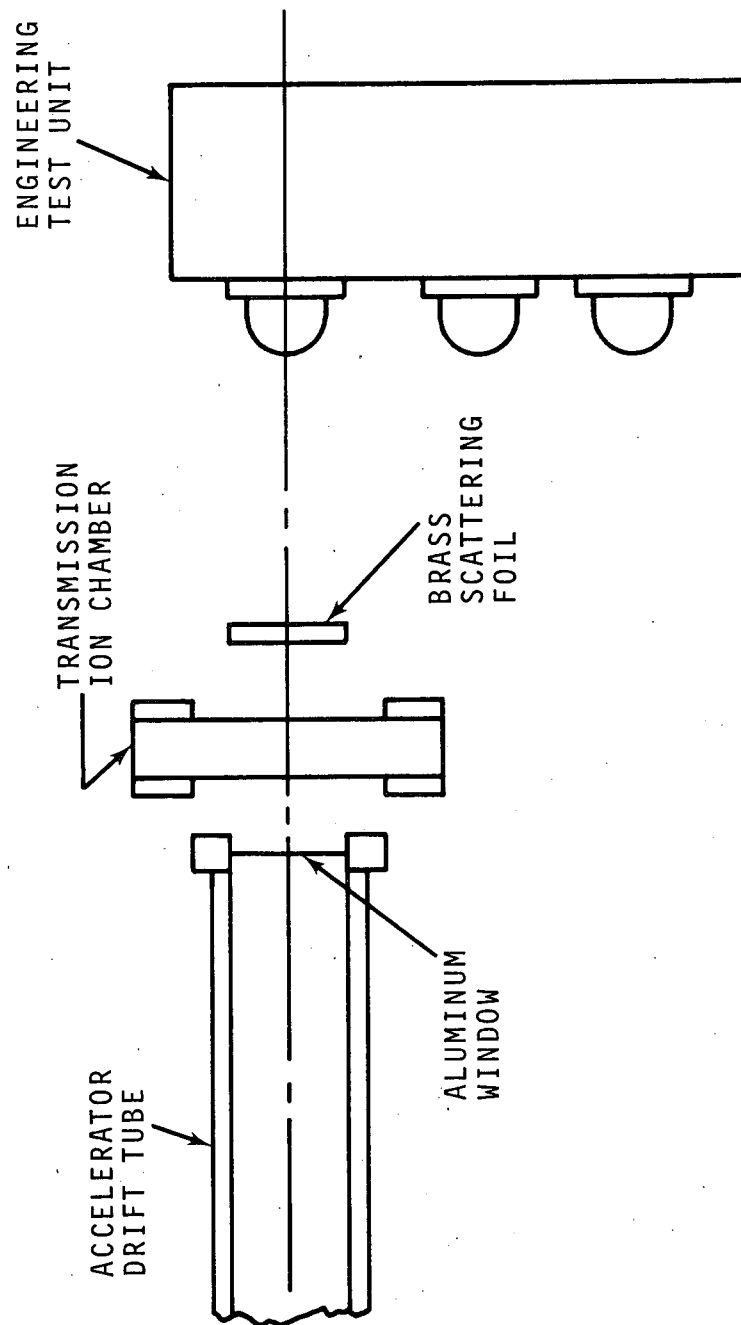


Figure 16.— Cyclotron Beam Scattering Configuration for End-To-End Test with Engineering Test Unit.

Table III End-to-End Test - Protons

Proton Energy	EPS Channel - Cts/Flux					
	1	2	3	4	5	6
130	.0286	.0302	.0310	.0327	.0335	.0389
90	.0351	.0353	.0355	.0355	.0376	.0401
73	.0371	.0376	.0382	.0382	--	--
42.9	.0410	.0417	.0413	.0438	--	--
35.3	.0400	.0406	.0406	--	--	--
33.6	.0394	.0396	.0398	--	--	--
23.3	.0395	.0410	.0074			

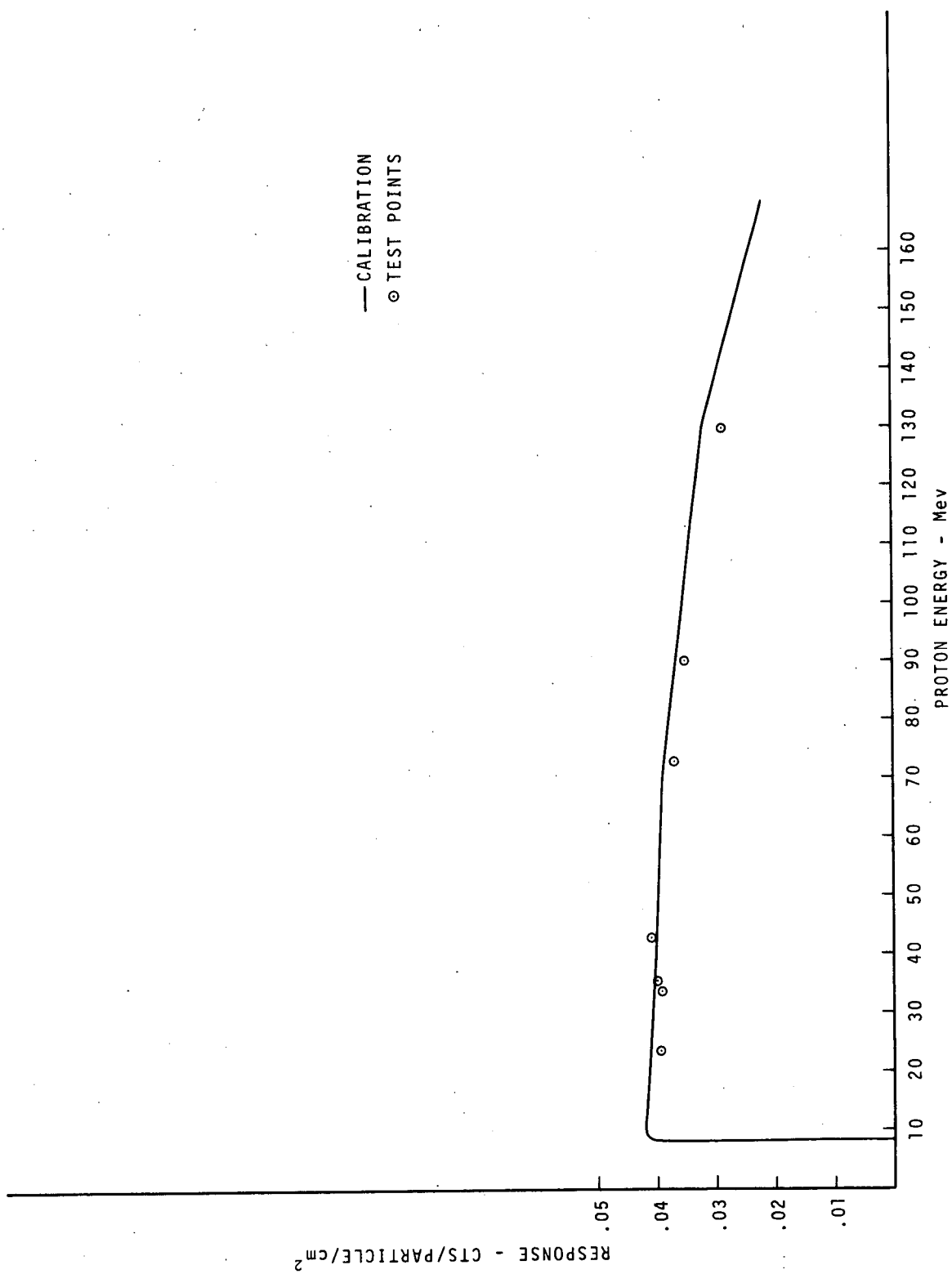


Figure 17. - End-To-End Test, Channel 1, Protons.

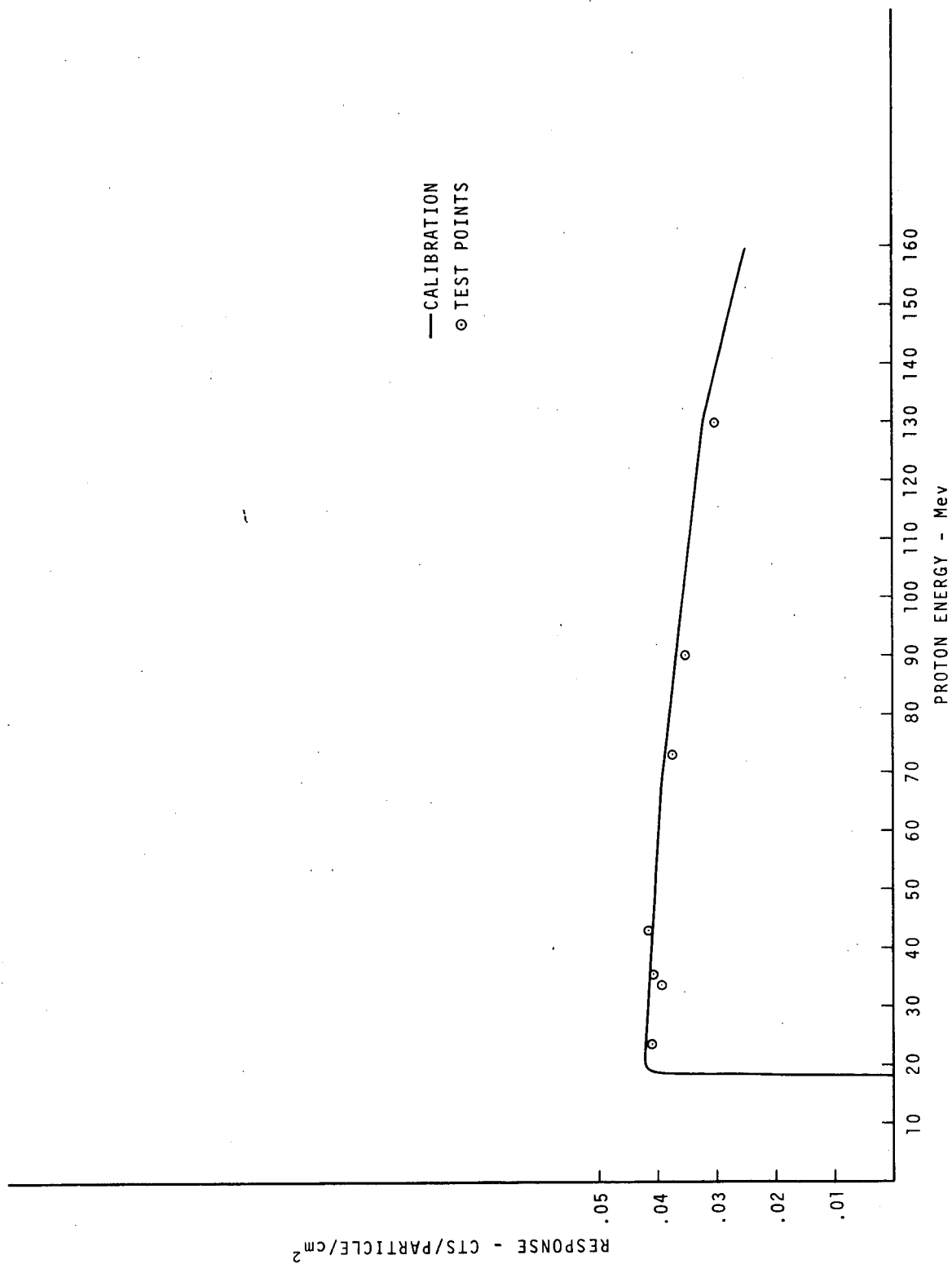


Figure 18. — End-To-End Test, Channel 2, Protons.

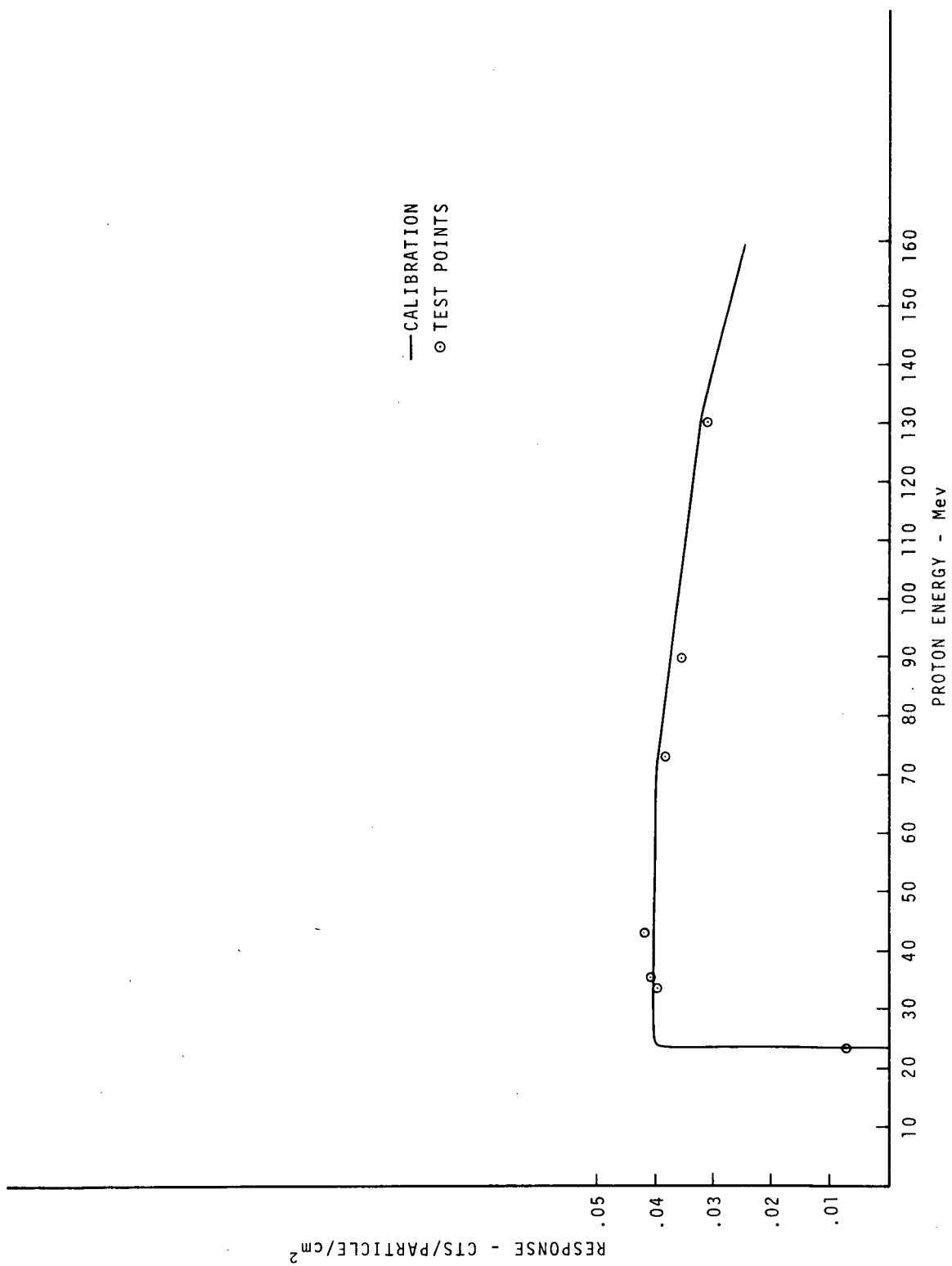


Figure 19. — End-To-End Test, Channel 3, Protons.

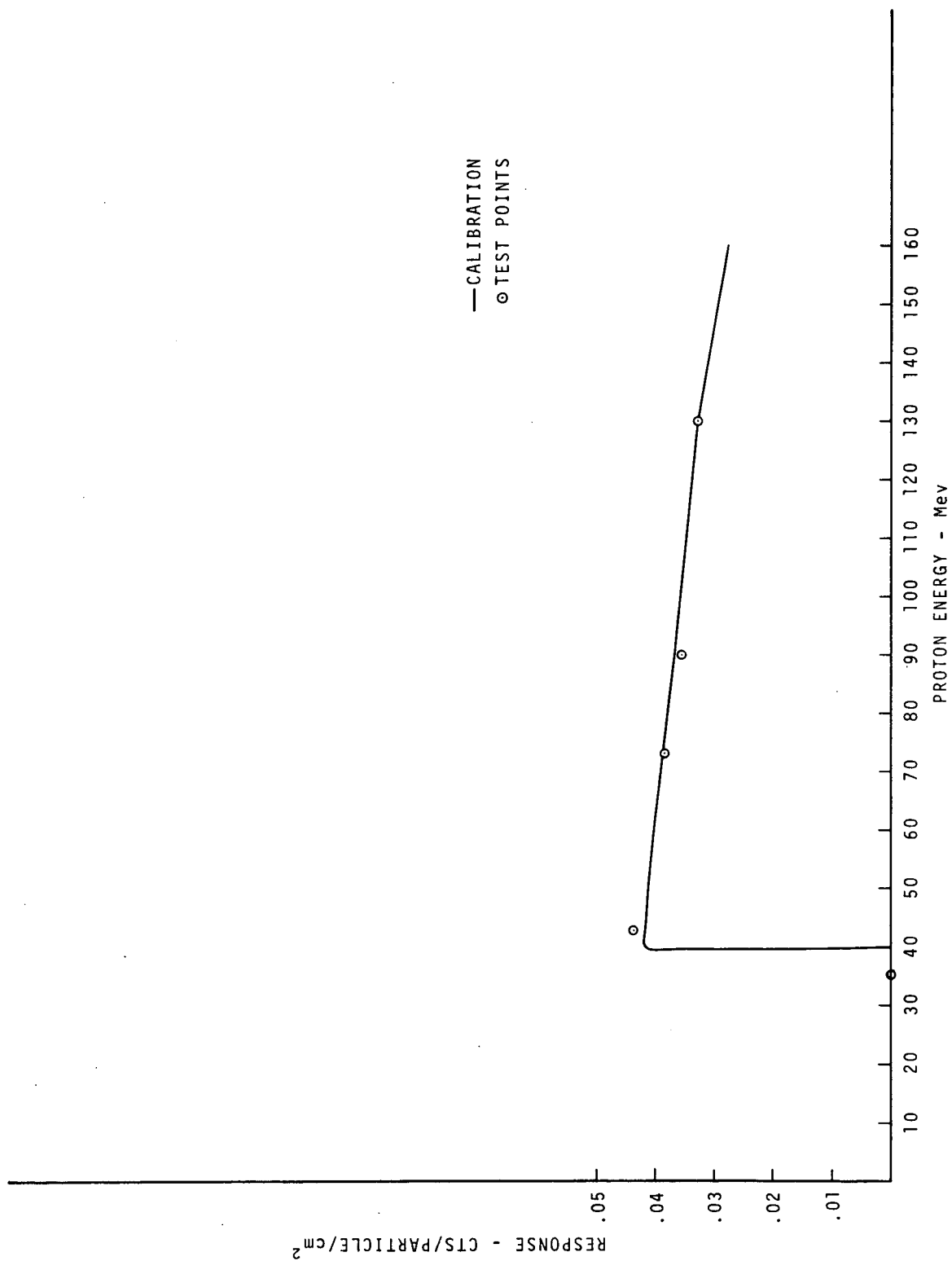


Figure 20. — End-To-End Test, Channel 4, Protons.

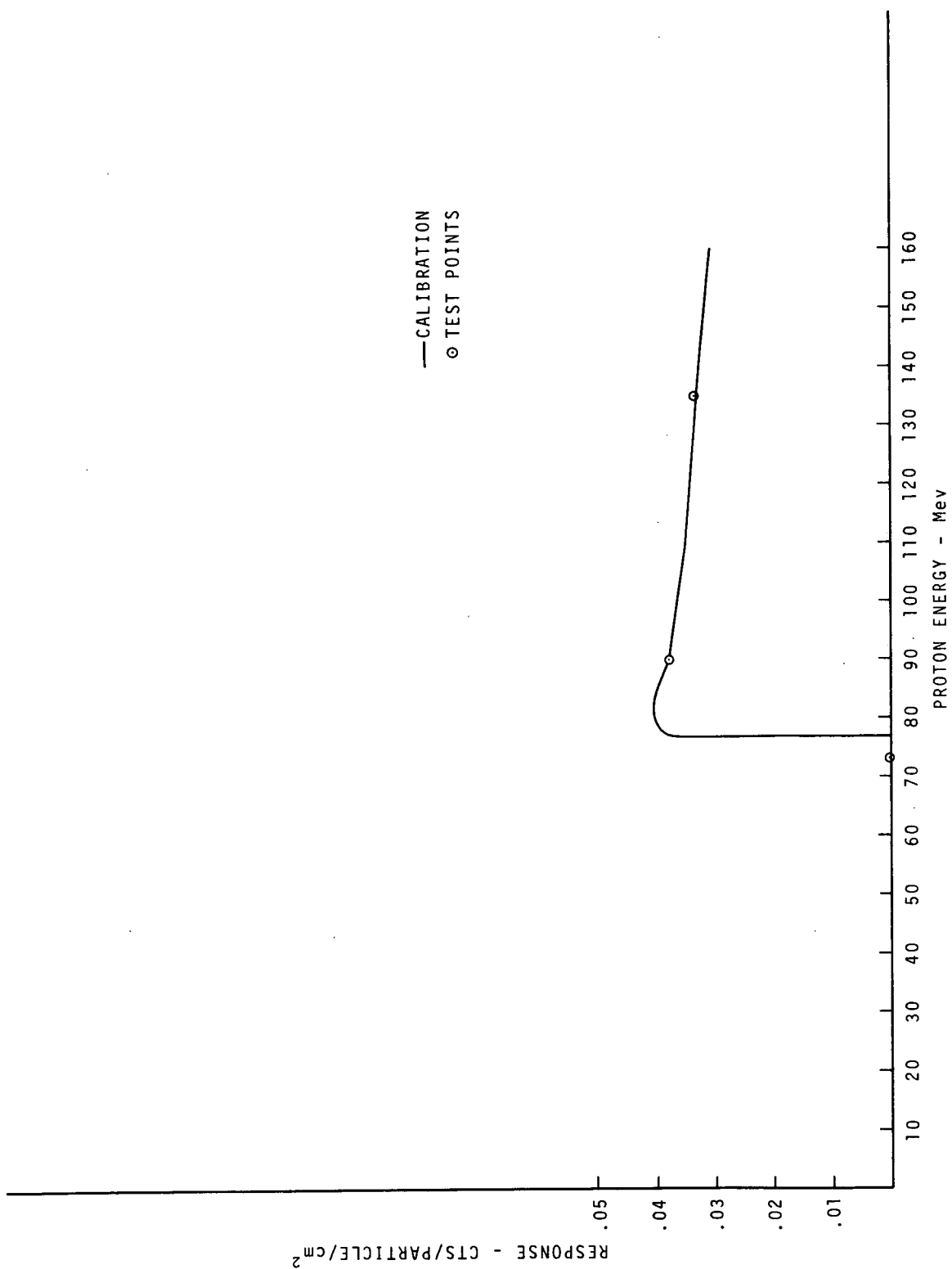


Figure 21. — End-To-End Test, Channel 5, Protons.

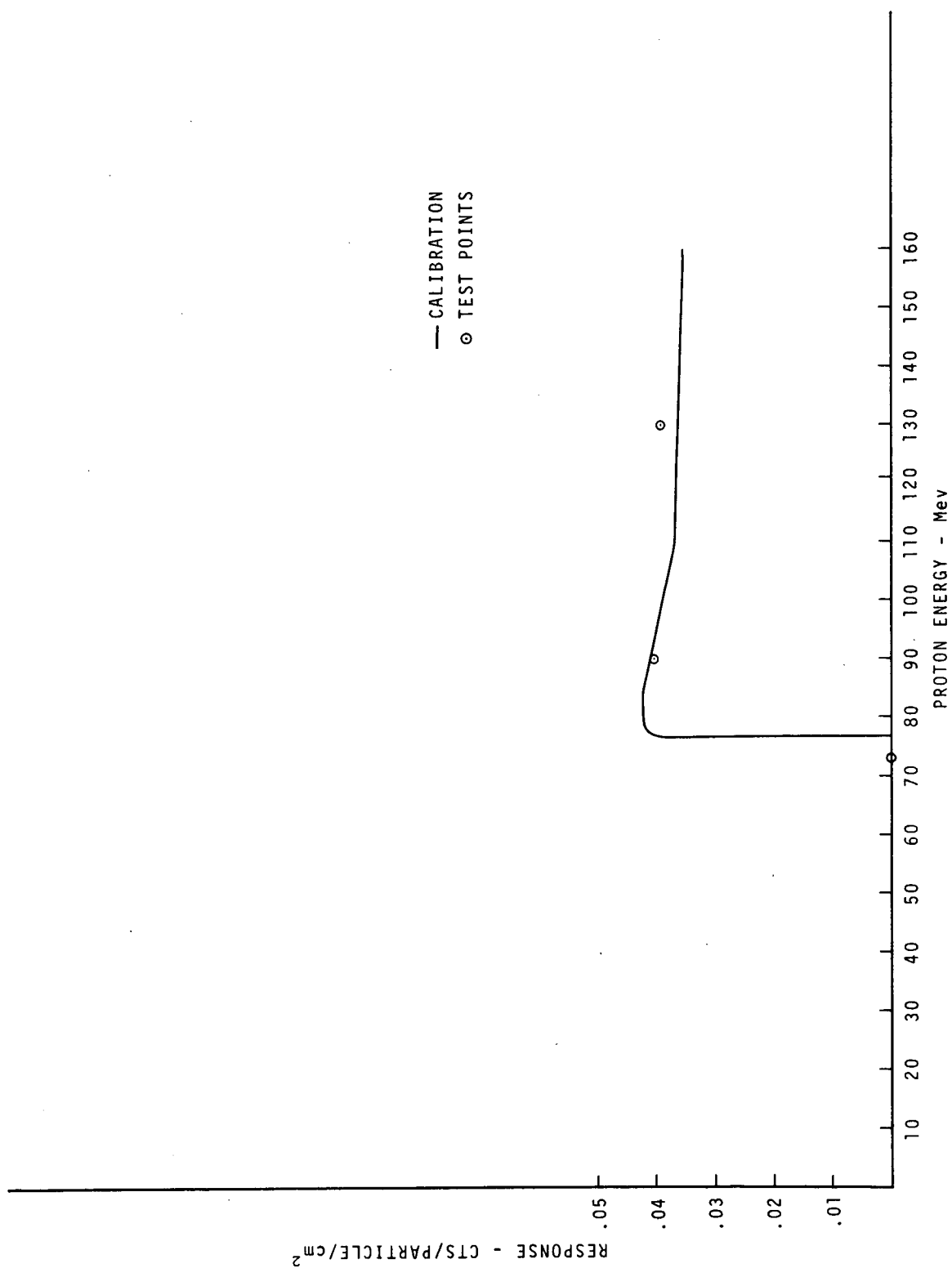


Figure 22. — End-To-End Test, Channel 6, Protons.

Except for two points (both at 130 MeV, one on channel 1 and one on channel 6), the values fall within about 5% of the calibration curves. (See section 3.2 for a discussion of the sources of errors.) However, a more meaningful way to compare the test results with the calibration responses is on the basis of their response to a standard spectrum over the same energy range. Such a standard spectrum for Skylab is shown in Figure 23. If $\phi(E)$ is the differential proton spectrum and $\epsilon G(E)$ is the response function for a particular spectrometer channel, the number of counts, R , from the channel is given by

$$R = \int_{E_0}^{E_{\max}} \epsilon G(E) \phi(E) dE$$

where the integral is taken over the region of interest for each channel. The value of R was determined for each channel for both the calibration response curve and the test response curve. Table IV lists the ratios of the test response to the calibration response for each of the six channels.

Table IV Indicated Response of Test Unit
To Orbital Proton Spectrum

Channel	Response Relative to Calibration
1	0.993
2	0.987
3	0.990
4	1.00
5	1.00
6	1.035

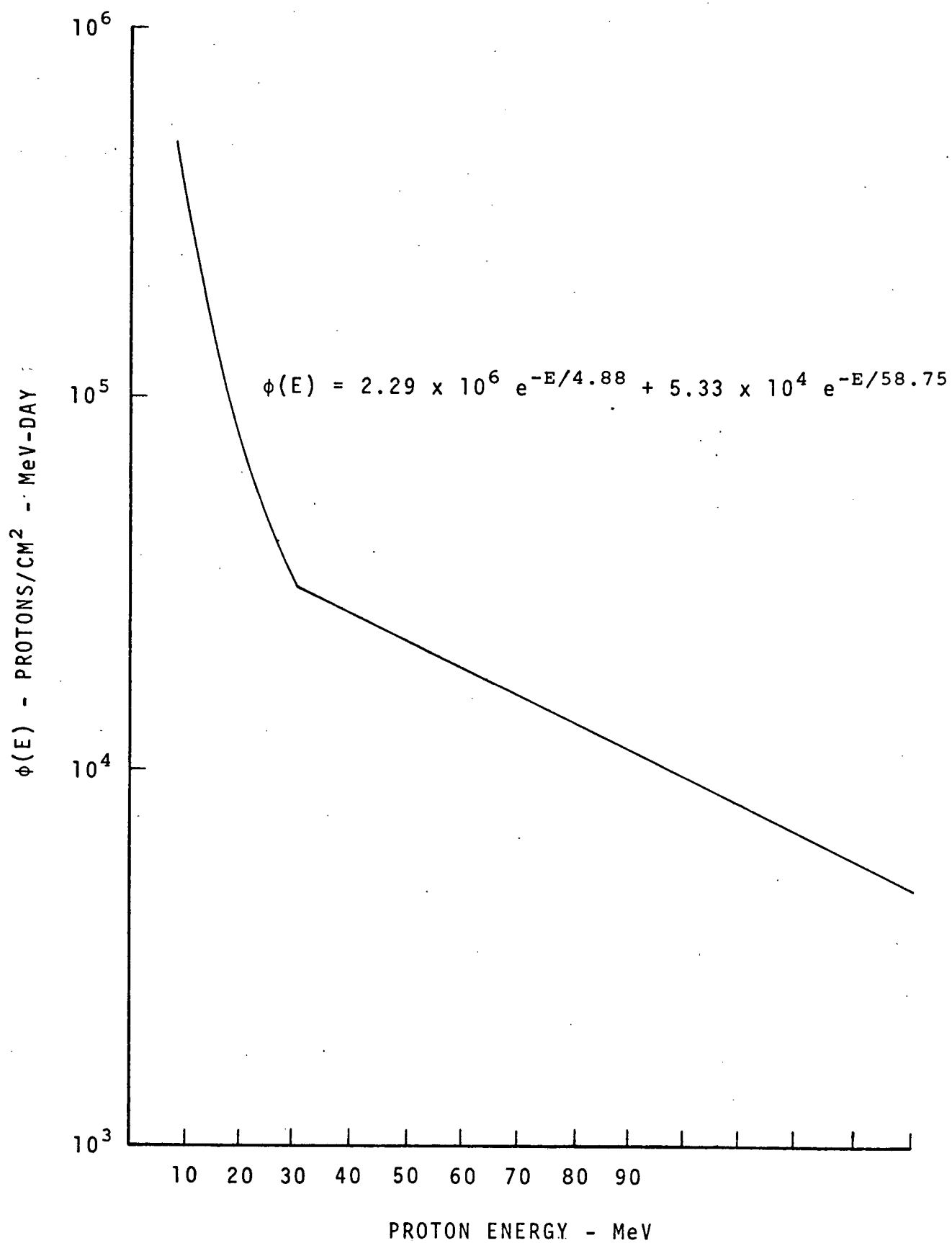


Figure 23. — Differential proton flux at 235 nautical miles.

3.2 Proton Channel Errors

Four major sources contribute to the system errors for the proton channels of the EPS:

- a. measurement of the detector dimensions,
- b. measurement of the proton flux during the calibration,
- c. variation in the electronics, and
- d. variation in the response of the detectors available for use in the flight systems.

Repeated measurements on a group of detectors indicated that the error made in determining a detector dimension is approximately 2%. Combining the errors in quadrature for the three dimensions gives an overall error due to dimensional uncertainty of approximately 4%. Measurement of the proton flux during calibration was estimated to have an error of approximately 5%. The overall variation in the response due to the electronics is estimated to be 5%. The last error is due to the variation in the response of all the detectors constituting the population from which the flight detectors will be chosen. In an effort to approximate the future population of detectors, a group of 26 detectors were given exhaustive tests to determine the survival rate and response of available detectors. Of the original group, only 21 survived the tests and continued to function as nuclear detectors. All of the surviving detectors were irradiated with high energy protons in order to estimate their variation in response. These variations were folded into the response functions which were in turn applied to the nominal Skylab proton spectrum, Figure 23, to determine an overall countrate. The range of variation for the detectors is given in Table V.

Table V Errors Due to Detector Variances

Channel #	Errors
1	$\pm 3\%$
2	$\pm 4\%$
3	$\pm 5\%$
4	$\pm 6\%$
5	$\pm 7\%$
6	$\pm 7\%$

The effects of the four types of errors are shown in Table VI.

Table VI Proton Error Summary - Percent

Channel #	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
Detector Dimension	4	4	4	4	4	4
Calibration	5	5	5	5	5	5
Electronics	5	5	5	5	5	5
Detector Variance	3	4	5	6	7	7
RMS Total	8.7	9.1	9.5	10.1	10.7	10.7

3.3 Electron Test

The electron portion of the End-to-End Test was performed at the National Bureau of Standards, Gaithersburg, Maryland, on the 4.0 MeV Van de Graaff accelerator. Each channel of the ETU was exposed to electrons within its range of sensitivity and the responses determined in counts/particle/cm². The results are given in Table VII. Only one point was run for channel 4 because the accelerator would not stay stable at higher energies. The responses are plotted for each of the channels in Figures 24 - 27. The calibration response for each channel, determined in section 2.2, is plotted on the same graphs as a solid line for comparison.

Table VII End-to-End Test - Electrons

Electron Energy	EPS Channel - Counts/Flux			
	1	2	3	4
3.88				.00121
3.70	.0447	.0447	.0393	--
2.71	.0495	.0390	.0221	--

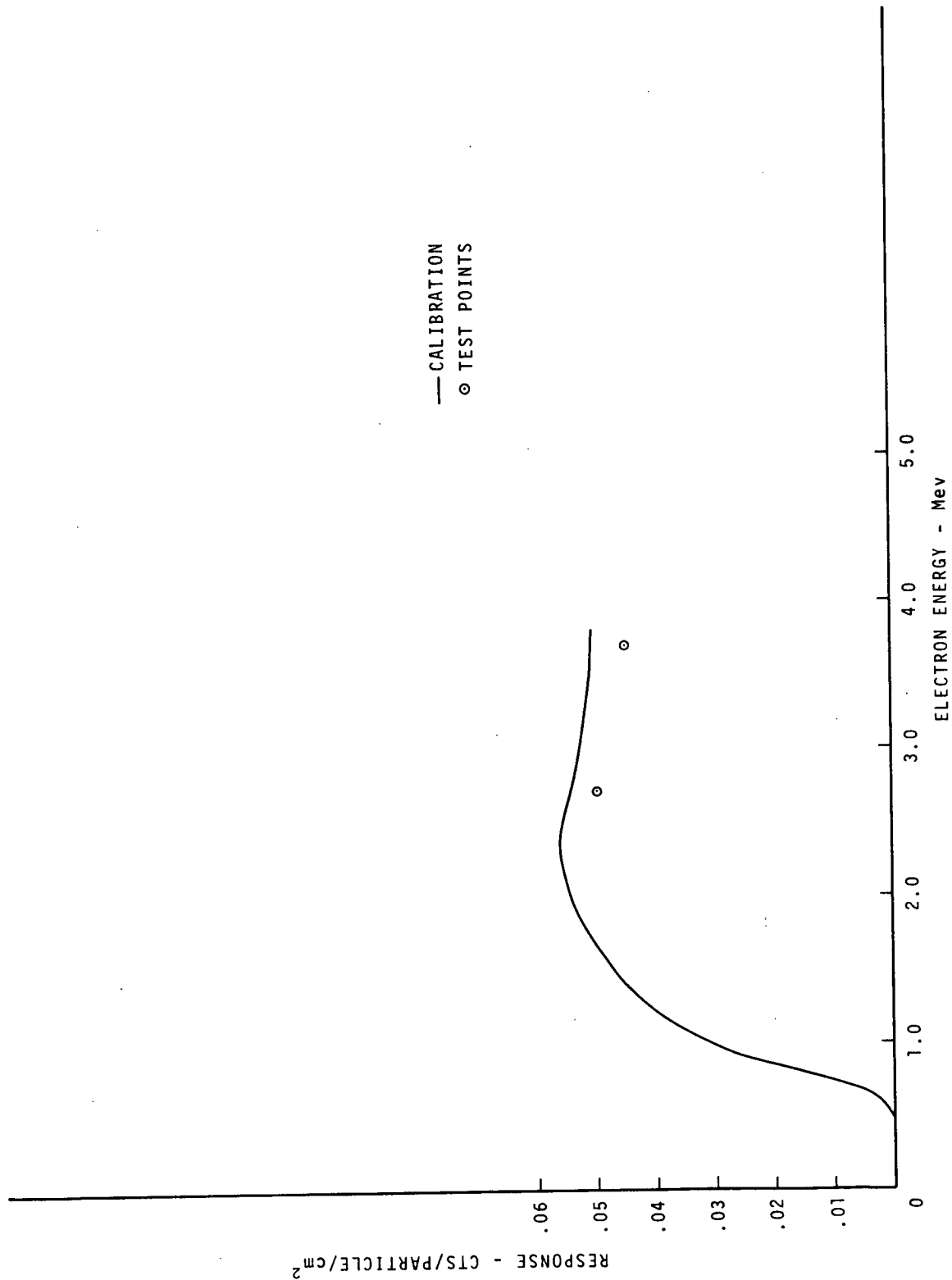


Figure 24. — End-To-End Test, Channel 1, Electrons.

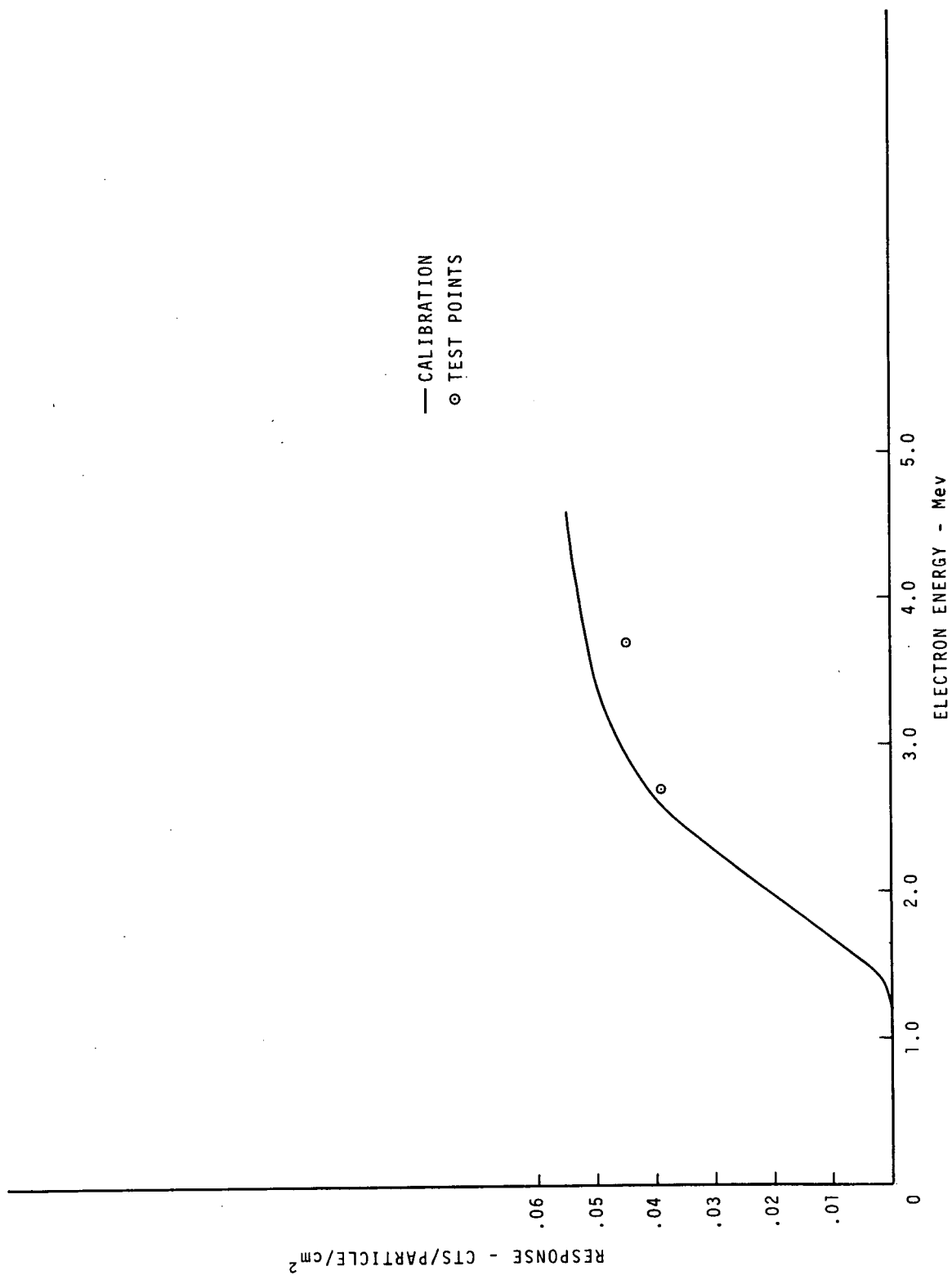


Figure 25. — End-To-End Test, Channel 2, Electrons.

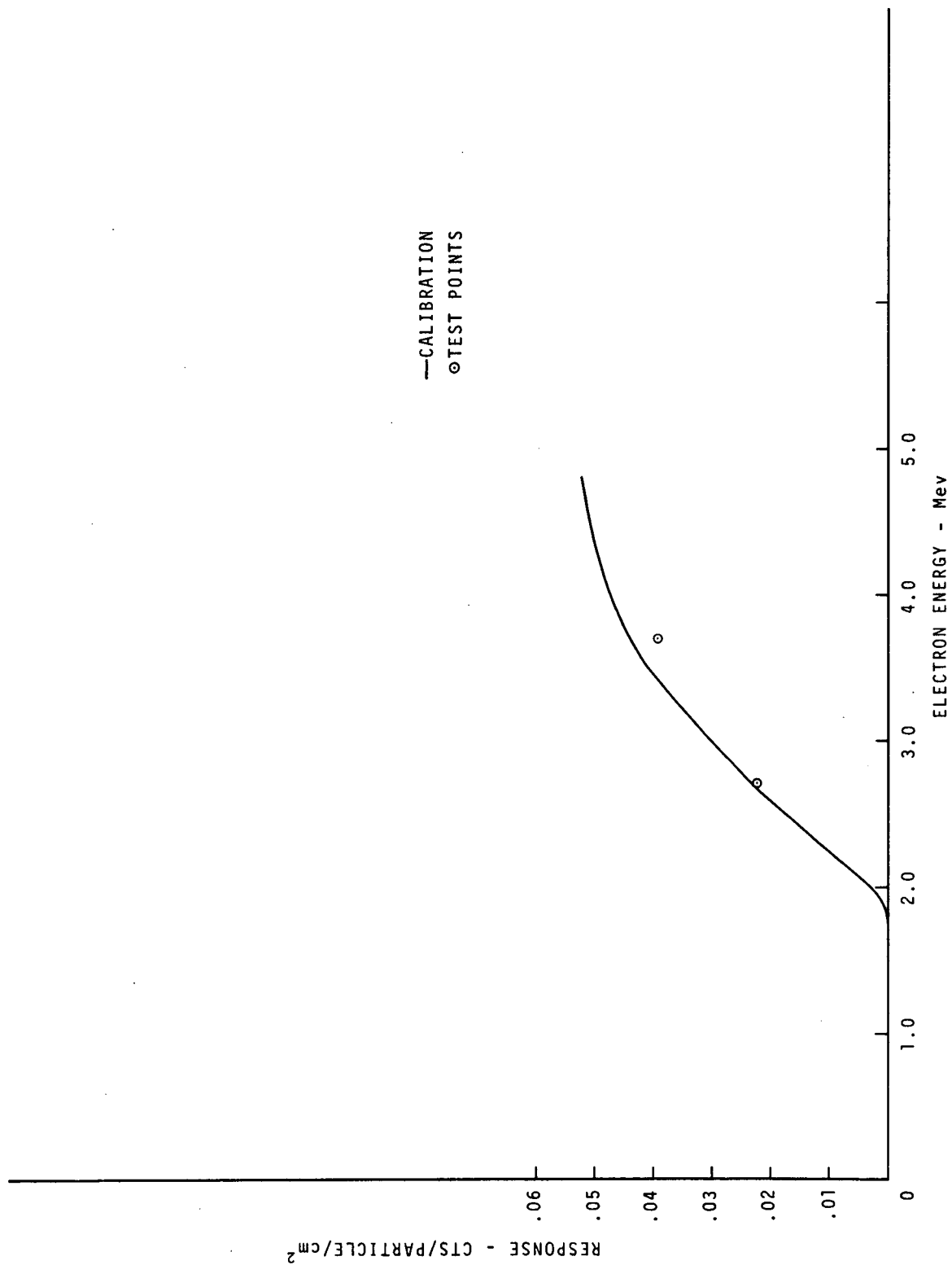


Figure 26. — End-To-End Test, Channel 3, Electrons.

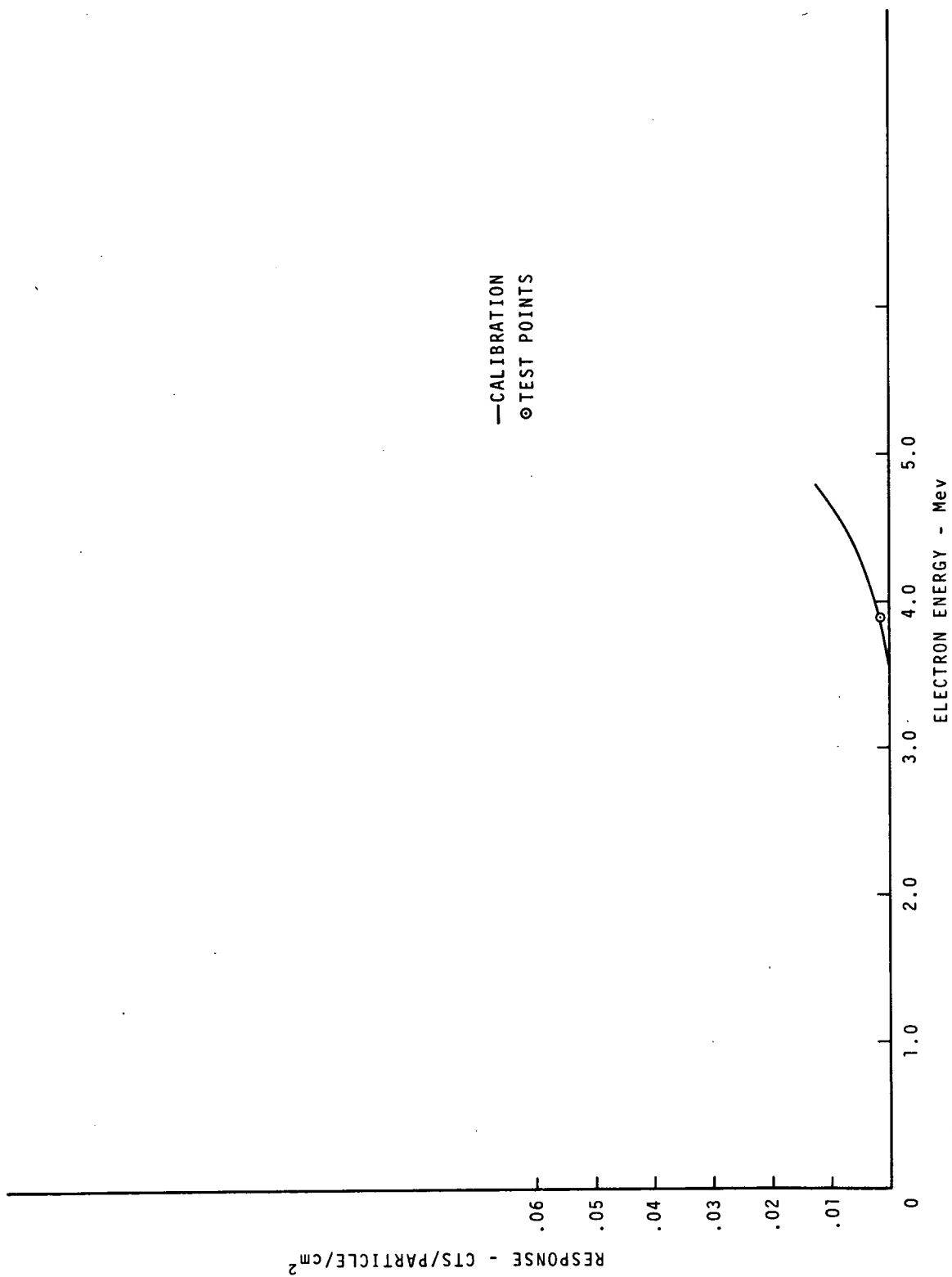


Figure 27. — End-To-End Test, Channel 4, Electrons.

3.4 Electron Channel Errors

Three major sources contribute to the system errors for the electron channels of the EPS:

- a. measurement of the detector dimensions,
- b. measurement of the electron flux during calibration
- c. variation in the electronics.

The fourth error source for the proton channels, that is due to variation in response of the detectors, is not significant in the electron channels due to the low discriminator level of 200 keV.

As in the case of the protons, the overall error due to dimensional uncertainties is approximately 4%. Measurement of the electron flux during calibration was estimated to have an error of approximately 5%. The overall variation in the response due to the electronics is estimated to be 5%. Summary of the errors is shown in Table VIII.

Table VIII Electron Error Summary - Percent

Channel #	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Detector Dimension	4	4	4	4
Calibration	5	5	5	5
Electronics	5	5	5	5
RMS Total - Test Unit	8.1	8.1	8.1	8.1
RMS Total - Calibration	6.4	6.4	6.4	6.4